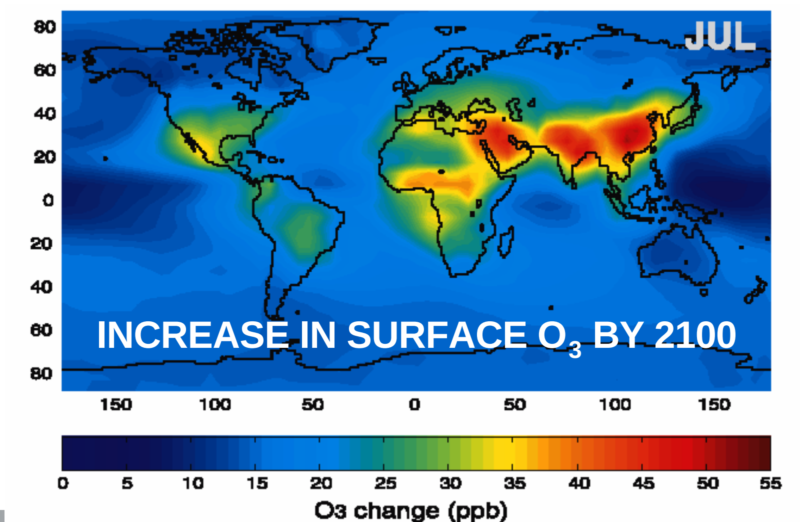
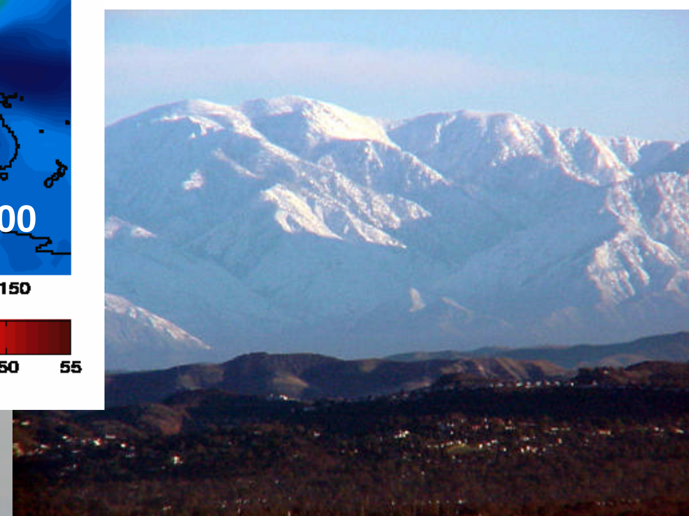
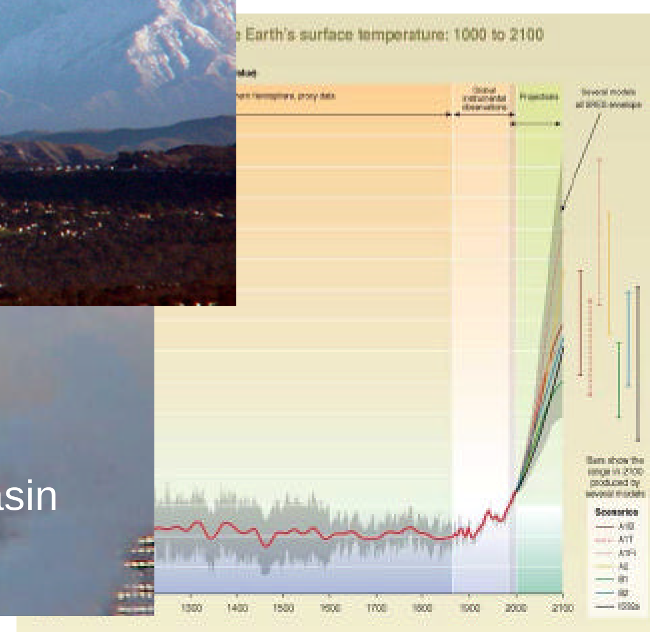
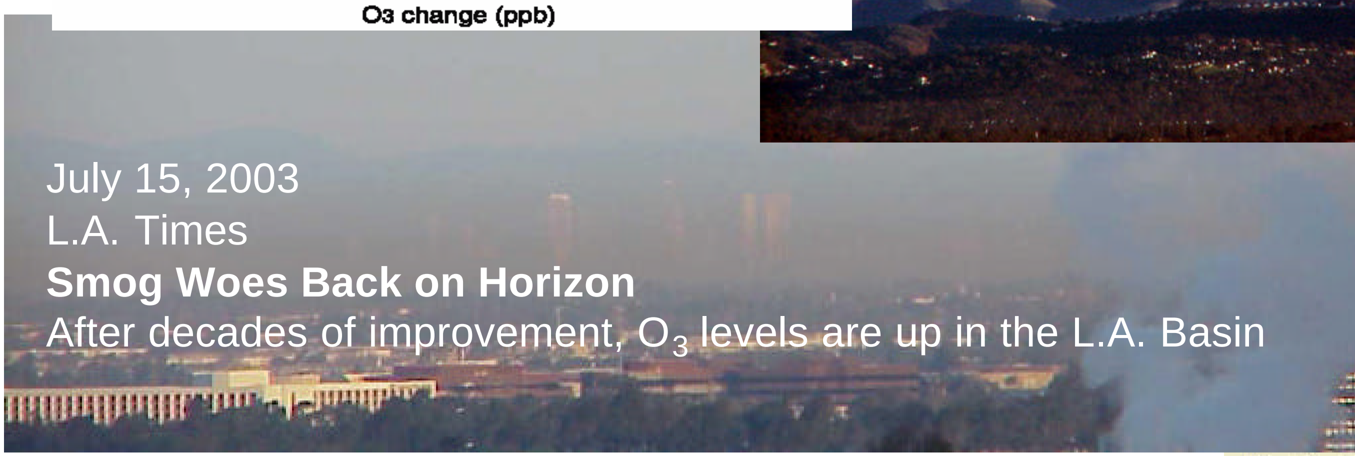
An Examination of Anthropogenic Climate Forcing in the 21st Century: Greenhouse Gases and Aerosols – Direct and Indirect

Michael Prather (UC Irvine) with the indirect help of many IPCC Authors









July 15, 2003
L.A. Times
Smog Woes Back on Horizon
After decades of improvement, O_3 levels are up in the L.A. Basin

An Examination of Anthropogenic Climate Forcing in the 21st Century: Greenhouse Gases and Aerosols – Direct and Indirect

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What is forcing the climate?

Attribution - Why do we care?

How do indirect effects work?

- within atmospheric chemistry
- across the Earth system

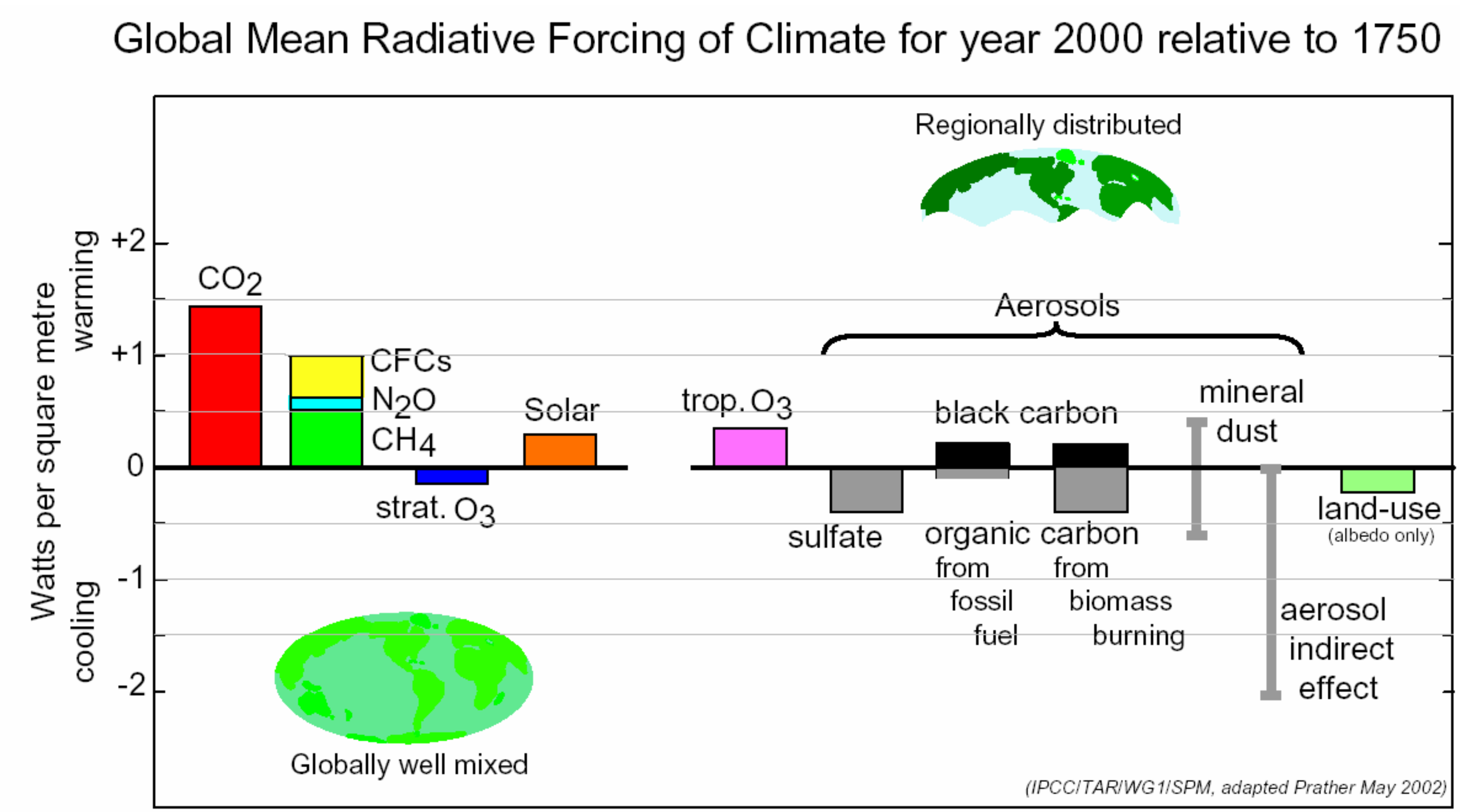
21st century scenarios

- SRES under attack?
- What is needed?

How can satellite observations help?

Feedbacks and cross-linkages

- Global Air Quality
- Mr. Clean H_2?



Global Mean Radiative Forcing of Climate for year 2000 relative to 1750
Regionally distributed
Watts per square metre
warming
cooling
+2
+1
0
-1
-2
CO_2
CFCs
N_2O
CH_4
strat. O_3
Solar
trop. O_3
Aerosols
sulfate
black carbon
organic carbon
from fossil fuel
from biomass burning
mineral dust
aerosol indirect effect
land-use
(albedo only)
Globally well mixed
(IPCC/TAR/WG1/SPM, adapted Prather May 2002)

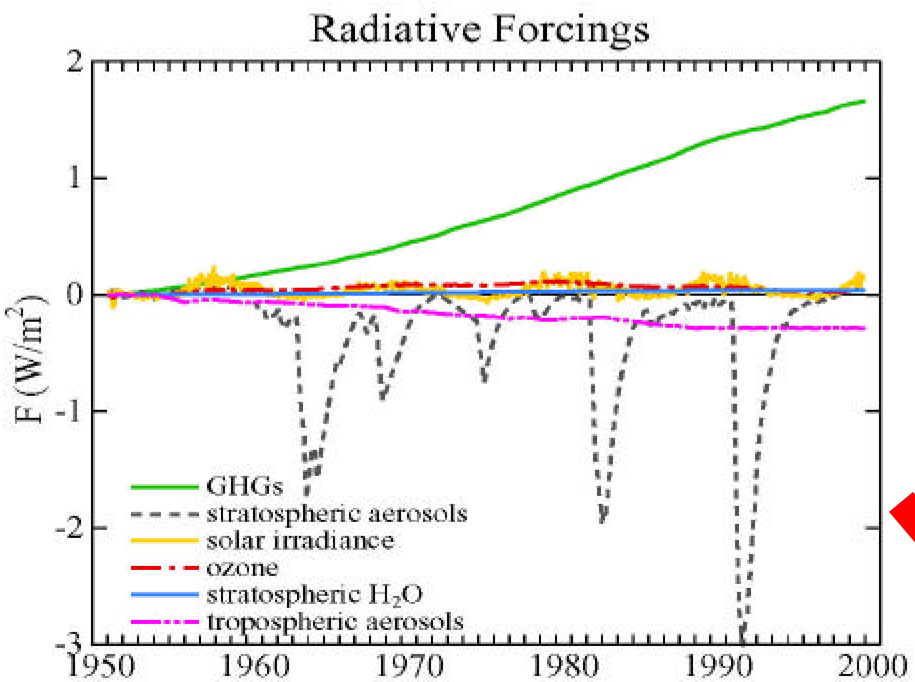


Figure 5. Climate forcing in the past 50 years due to six mechanisms (GHGs = long-lived greenhouse gases). The tropospheric aerosol forcing is very uncertain [Reference 1b].

J. Hansen et al., *JGR*, **107**, D18, 4347, 2002

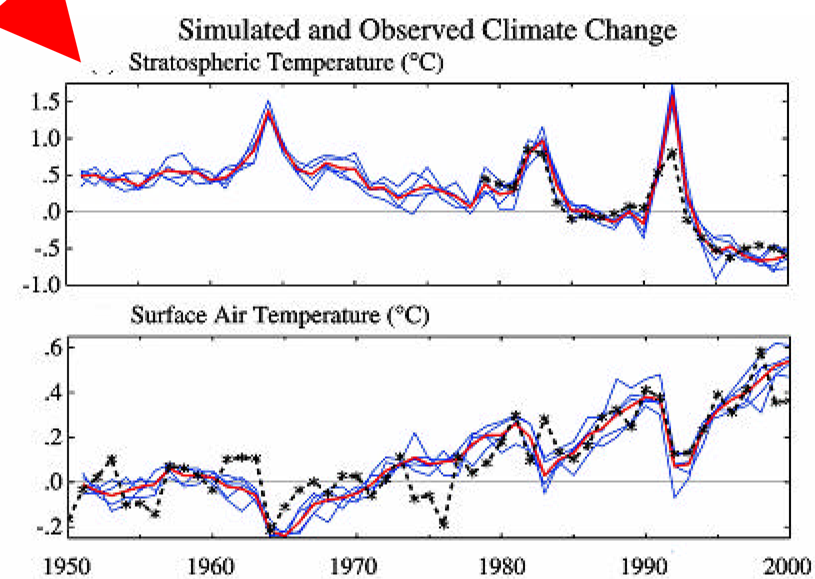


Figure 6. Simulated and observed global temperature change for 1951-2000 and simulated planetary energy imbalance [Reference 1b].

Attribution of Climate Change: Certainty

the historical approach

Sen. Gore sub-committee hearings 1988:

I am 99 per cent certain that we are now seeing global warming ....

James Hansen

Attribution of Climate Change: Cause
the IPCC SAR/TAR approach

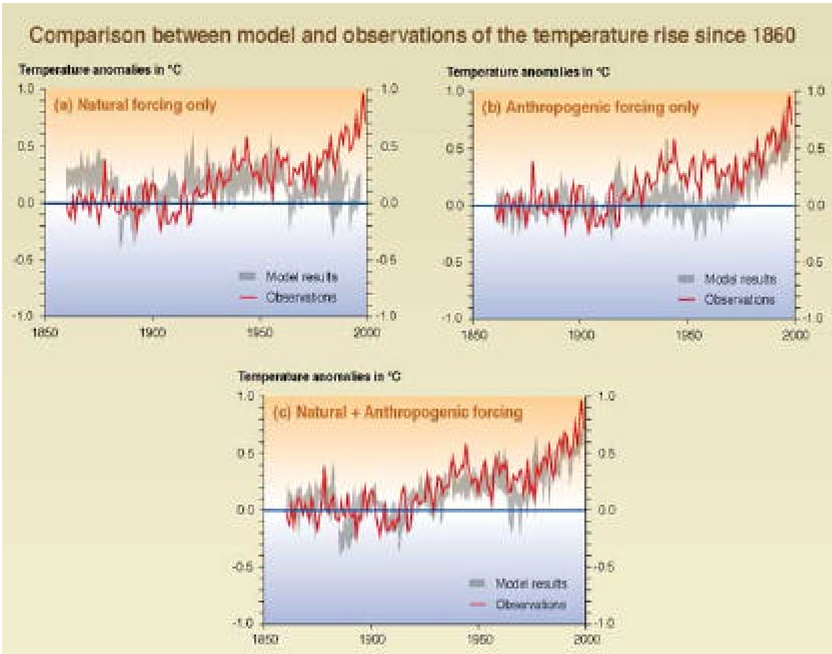
IPCC WG1 Second Assessment Report 1996:

The balance of evidence suggests that there is a discernible human influence on global climate.

IPCC Third Assessment Report 2001:

The Earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities.

There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.



Attribution of Climate Change: Blame
the UN FCCC Brazil Proposal

UNITED NATIONS

UNFCCC Framework Convention on Climate Change

During the negotiations of the Kyoto Protocol in 1997, the delegation of **Brazil** made a **proposal** for distributing the burden of emission reductions among Parties included in Annex I to the [Framework] Convention. Reductions towards an overall emission ceiling ... Among individual Annex I Parties proportional *to their relative share of responsibility for climate change*.

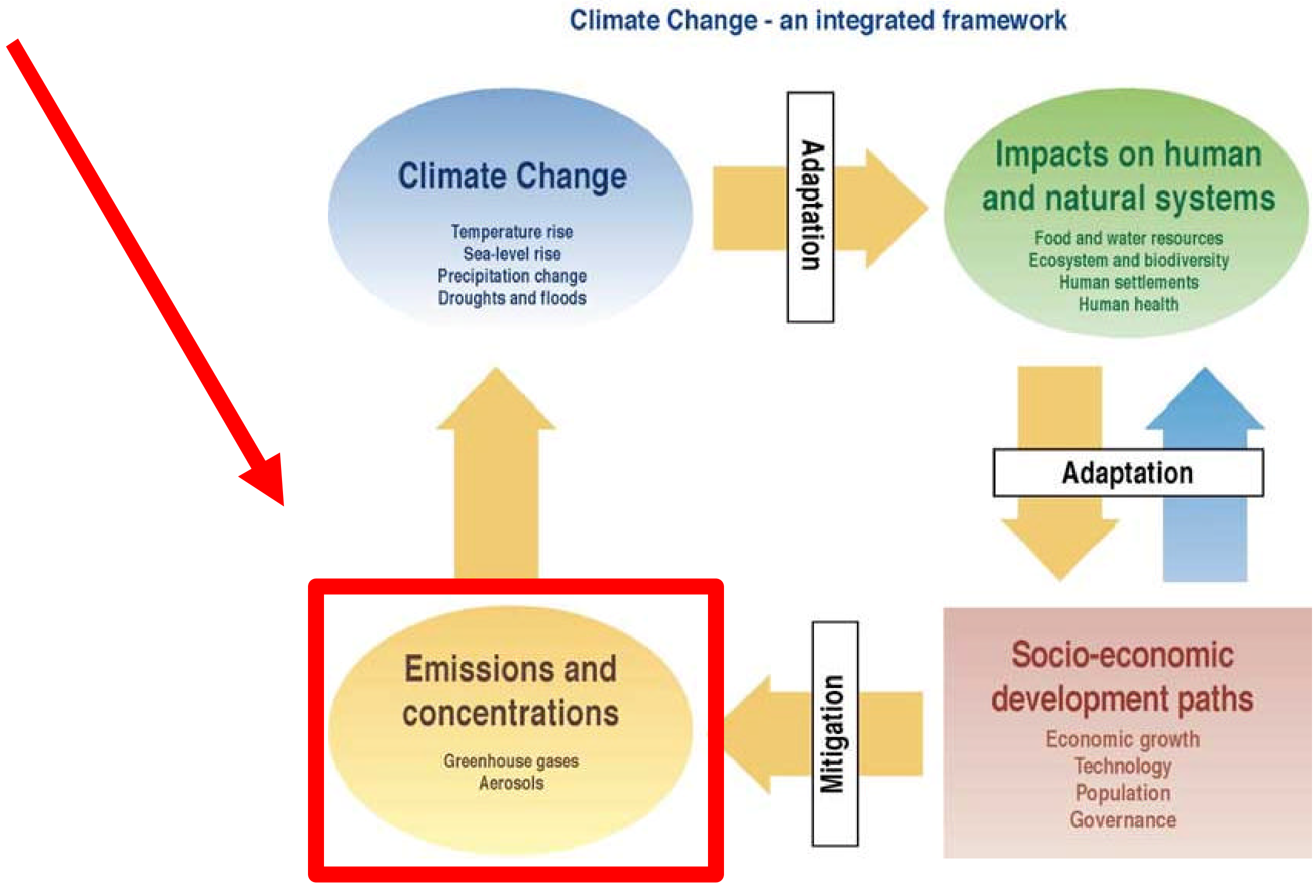
SBSTA (2002) noted that, for the purpose of *validating the models against observed climate*, the analysis should also include factors influencing global climate other than the greenhouse gases covered by the Convention and the Kyoto Protocol. *Thus we need national inventories for Kyoto and non-Kyoto greenhouse agents.*

Attribution of Climate Change: Avoidance

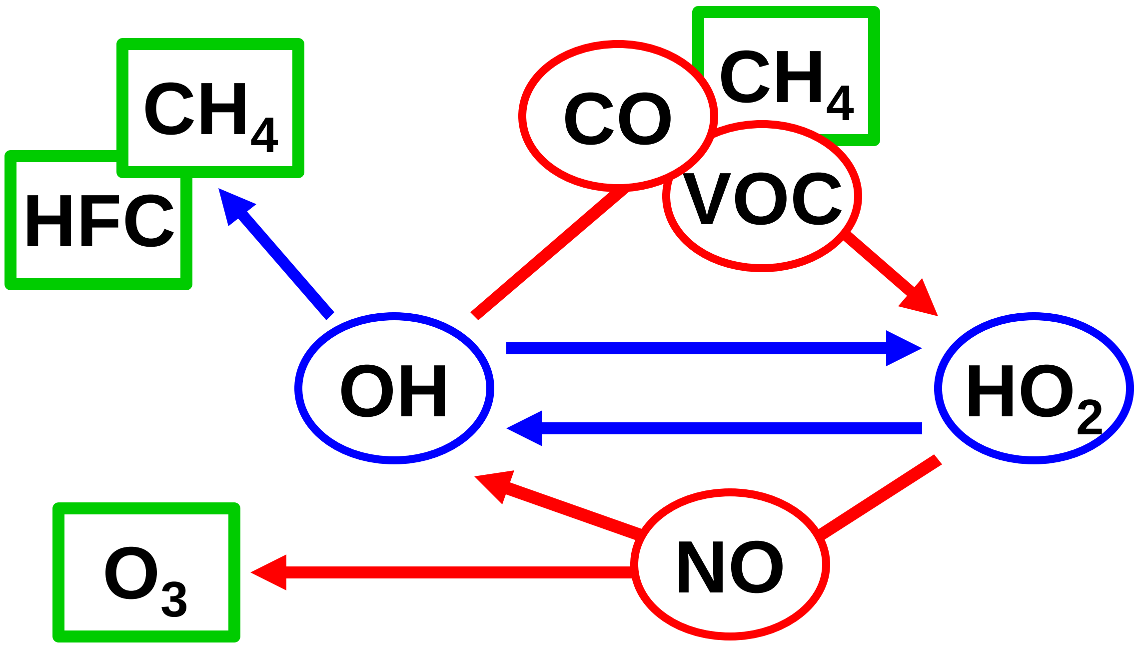
Belshazzar's Feast by Rembrandt

Climate Change involves the entire Earth system including ecosystems and human dimensions

This talk focuses on Atmospheric Composition



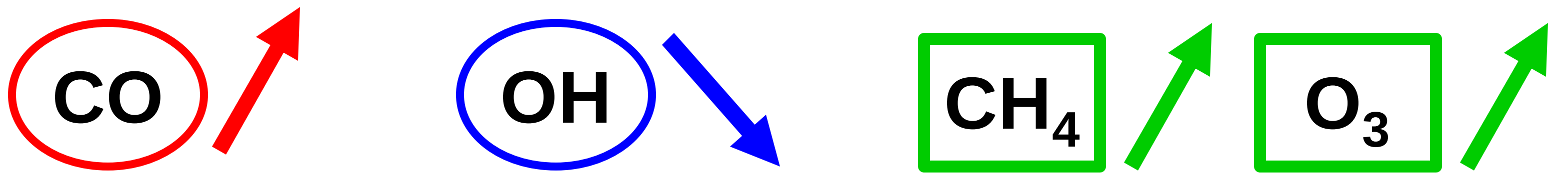
How do non-greenhouse Pollutants impact Climate ?

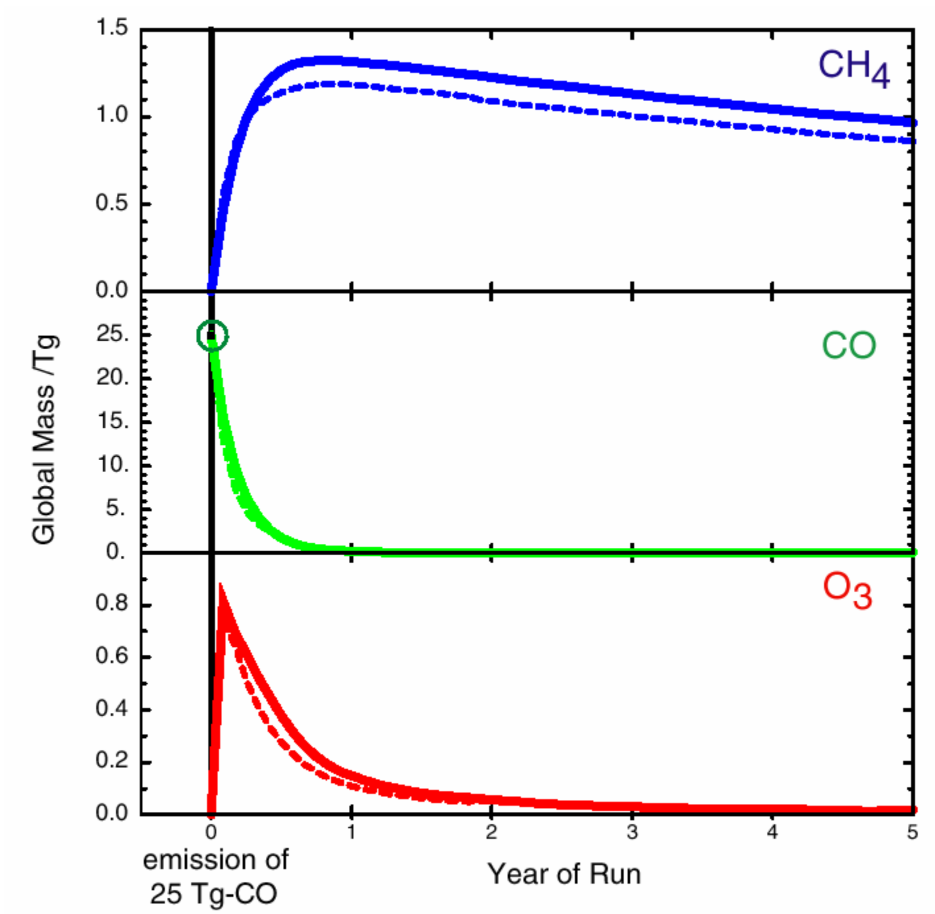


CO, VOC, NO_X *(=NO+NO$_2$)*, & CH_4 control

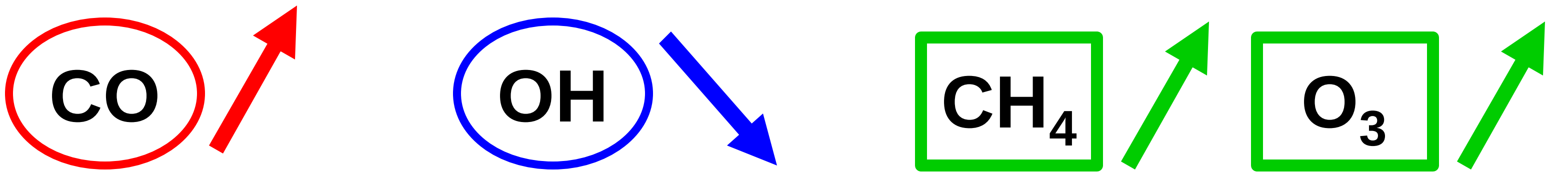
Tropospheric Chemistry

is the sink for CH_4 & HFCs; the source for O_3


CO
OH
CH4
O3


1.5
1.0
0.5
0.0
CH4
25.
20.
15.
10.
5.
0.
CO
0.8
0.6
0.4
0.2
0.0
O3
Global Mass /Tg
0
1
2
3
4
5
emission of
25 Tg-CO
Year of Run

CO becomes an indirect greenhouse gas



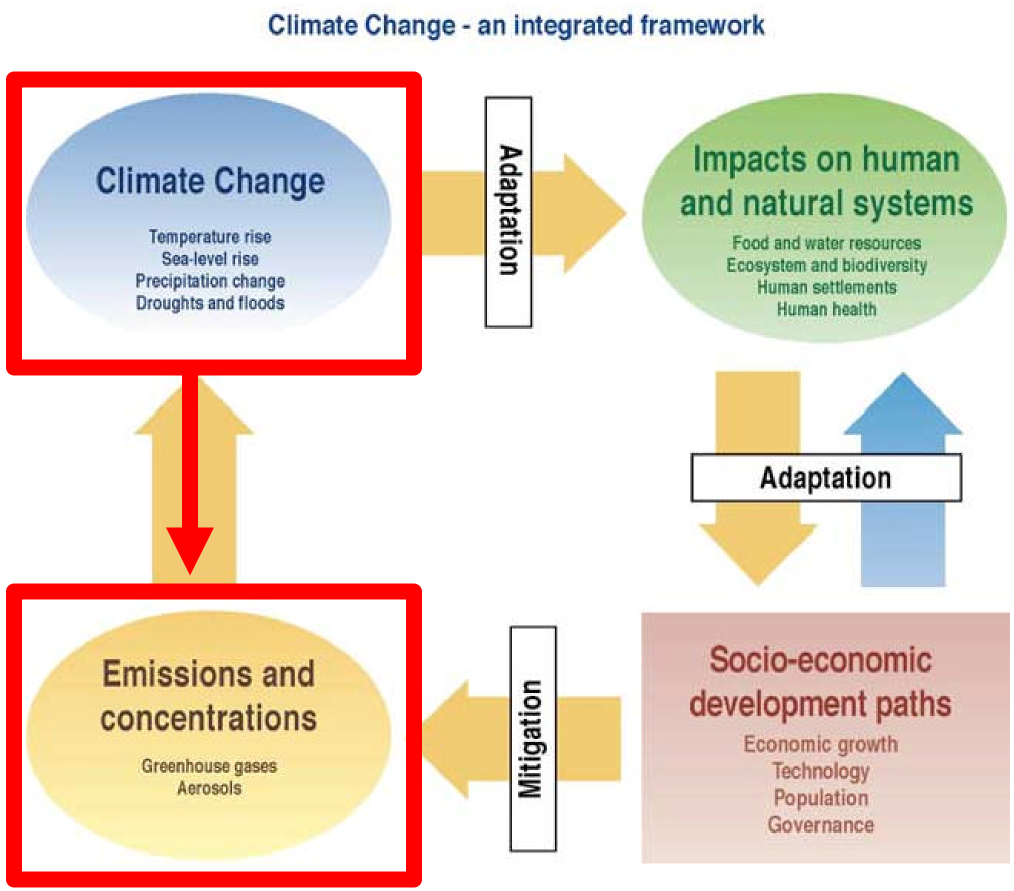
CO emissions are effectively equivalent to CH_4 emissions:

100 Tg-CO = 5 Tg-CH4

(IPCC, TAR)

Climate Change involves the entire Earth system including ecosystems and human dimensions

What about feedbacks on composition?



GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 9, PAGES 1723-1726, MAY 1, 2001

Role of climate feedback on methane and ozone studied with a coupled Ocean-Atmosphere-Chemistry model.

C. E. Johnson, D. S. Stevenson[1], W. J. Collins[2], and R. G. Derwent[2]

Met Office, Hadley Centre for Climate Prediction and Research, UK

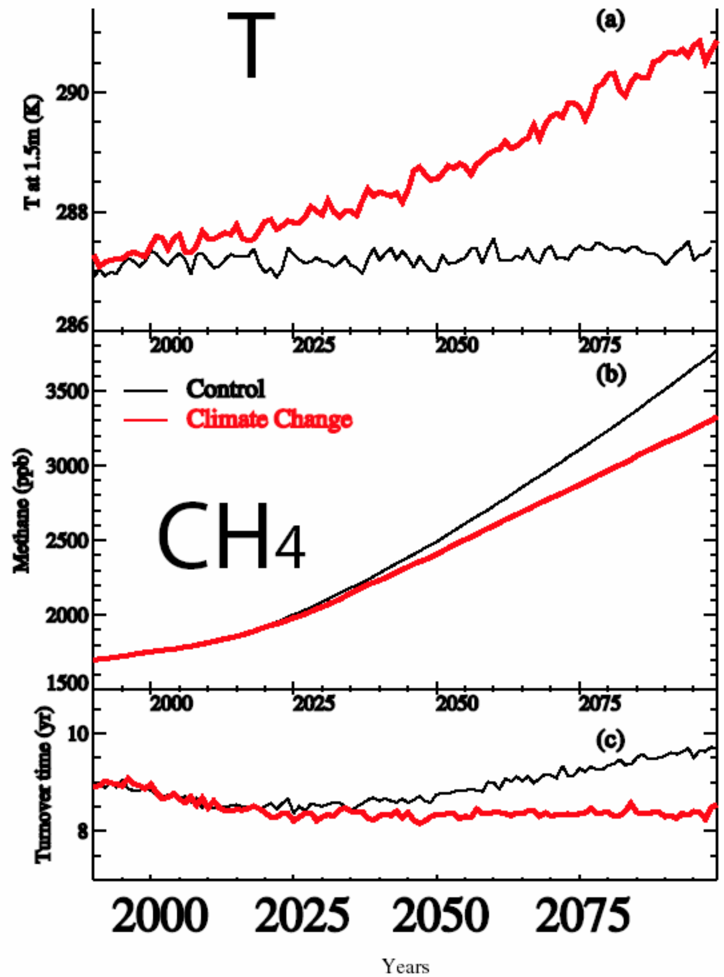


Figure 1. Global mean temperature at 1.5 m simulated over the period 1990-2100 in the control and climate change experiments (a), global mean methane concentrations (b), and the global mean methane lifetime in years (c).

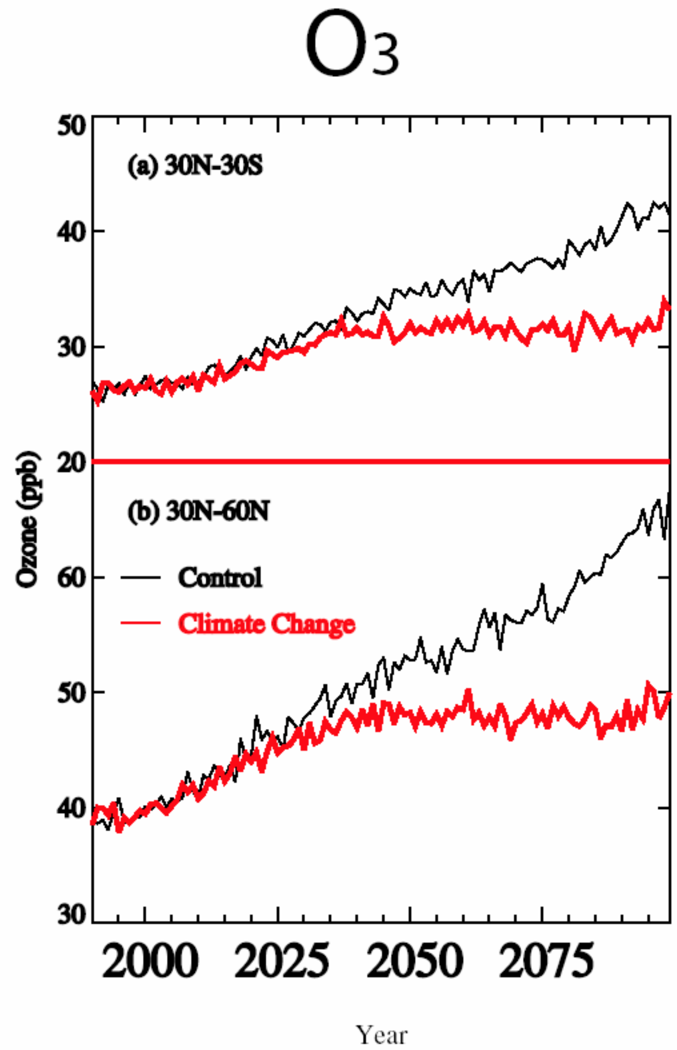
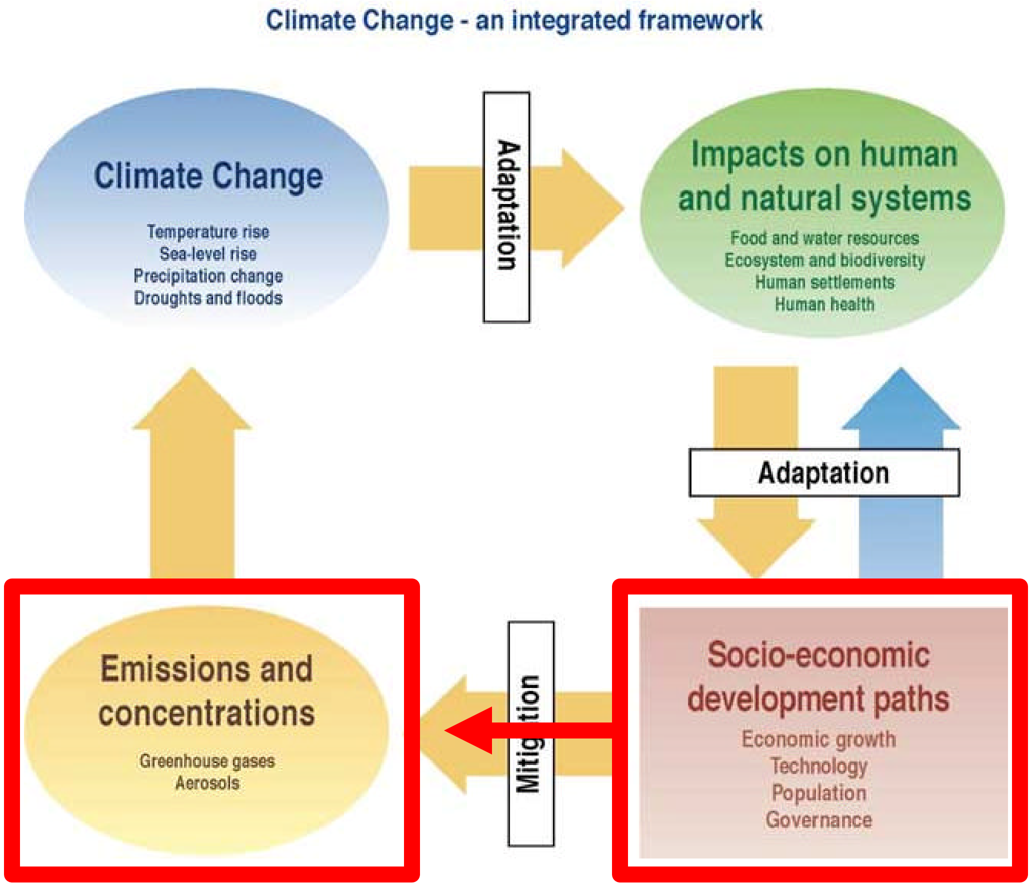
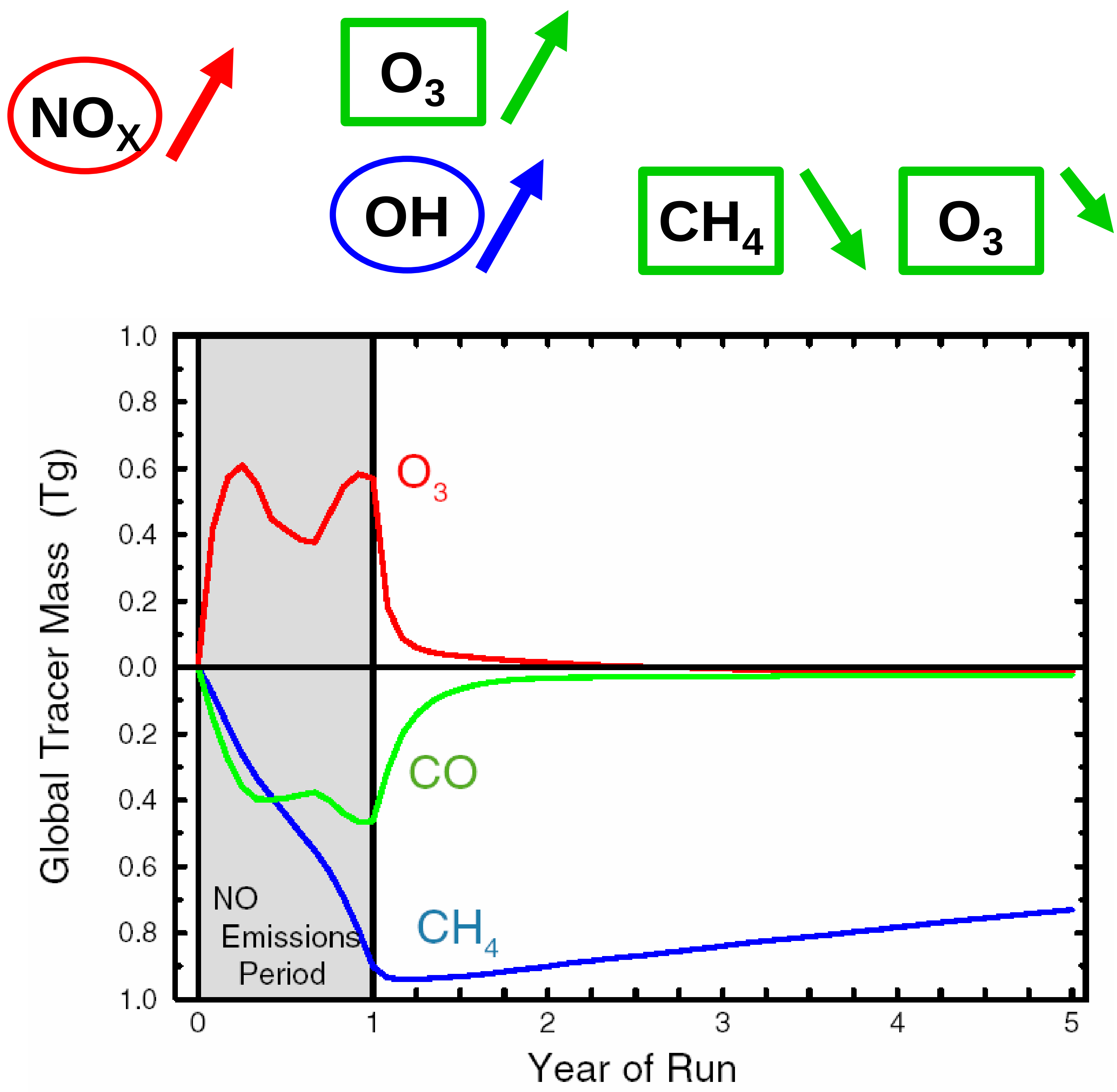


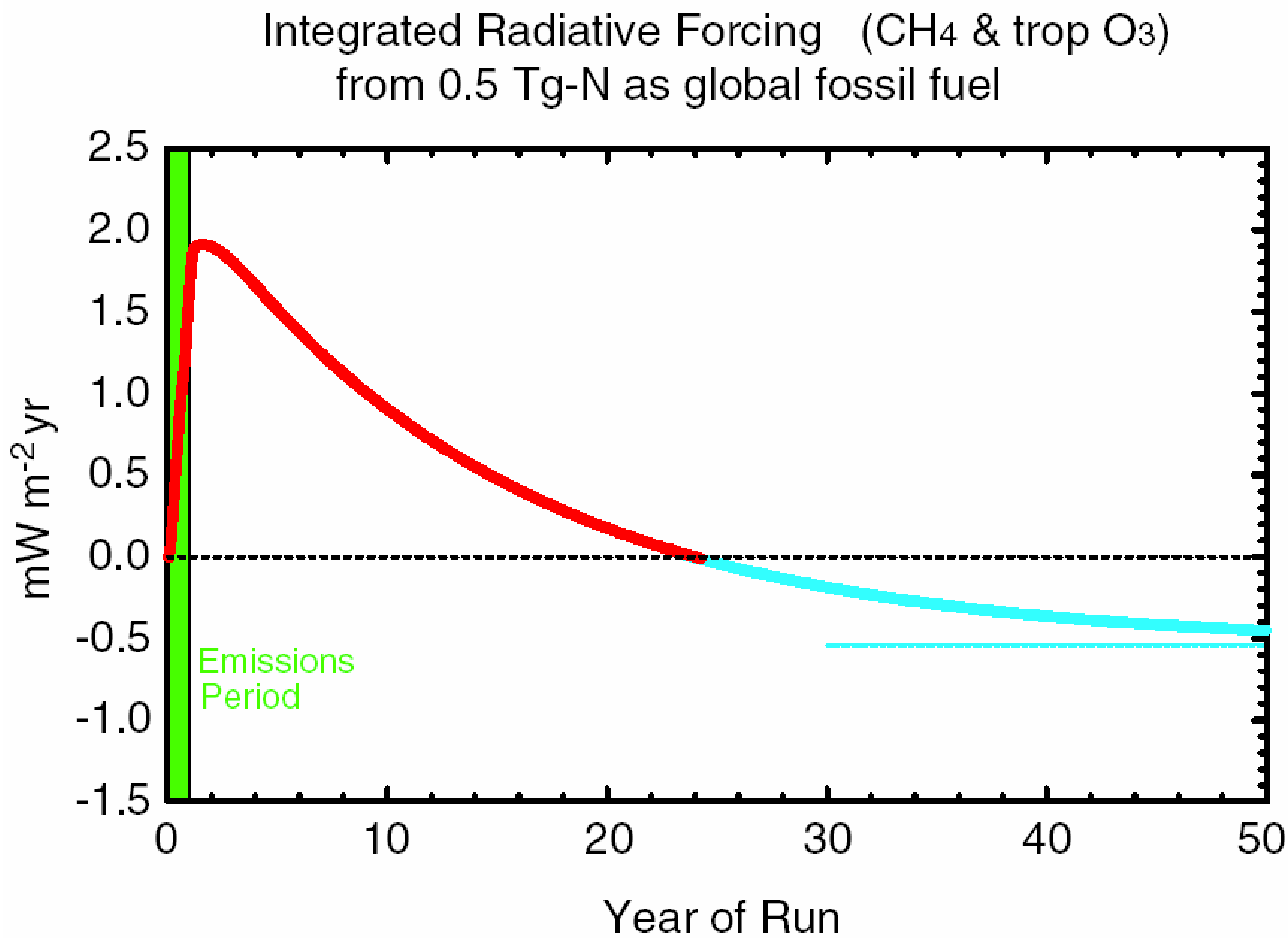
Figure 2. Zonal mean 650 hPa ozone concentrations for (a) 30 S-30 N and (b) 30-60 N in July simulated over the period 1990-2099 using control and SRES A2 climate experiments.

Climate Change involves the entire Earth system including ecosystems and human dimensions

How much detail is needed for emissions?




NOx
O3
OH
CH4
O3
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Global Tracer Mass (Tg)
O3
CO
CH4
NO Emissions Period
0
1
2
3
4
5
Year of Run



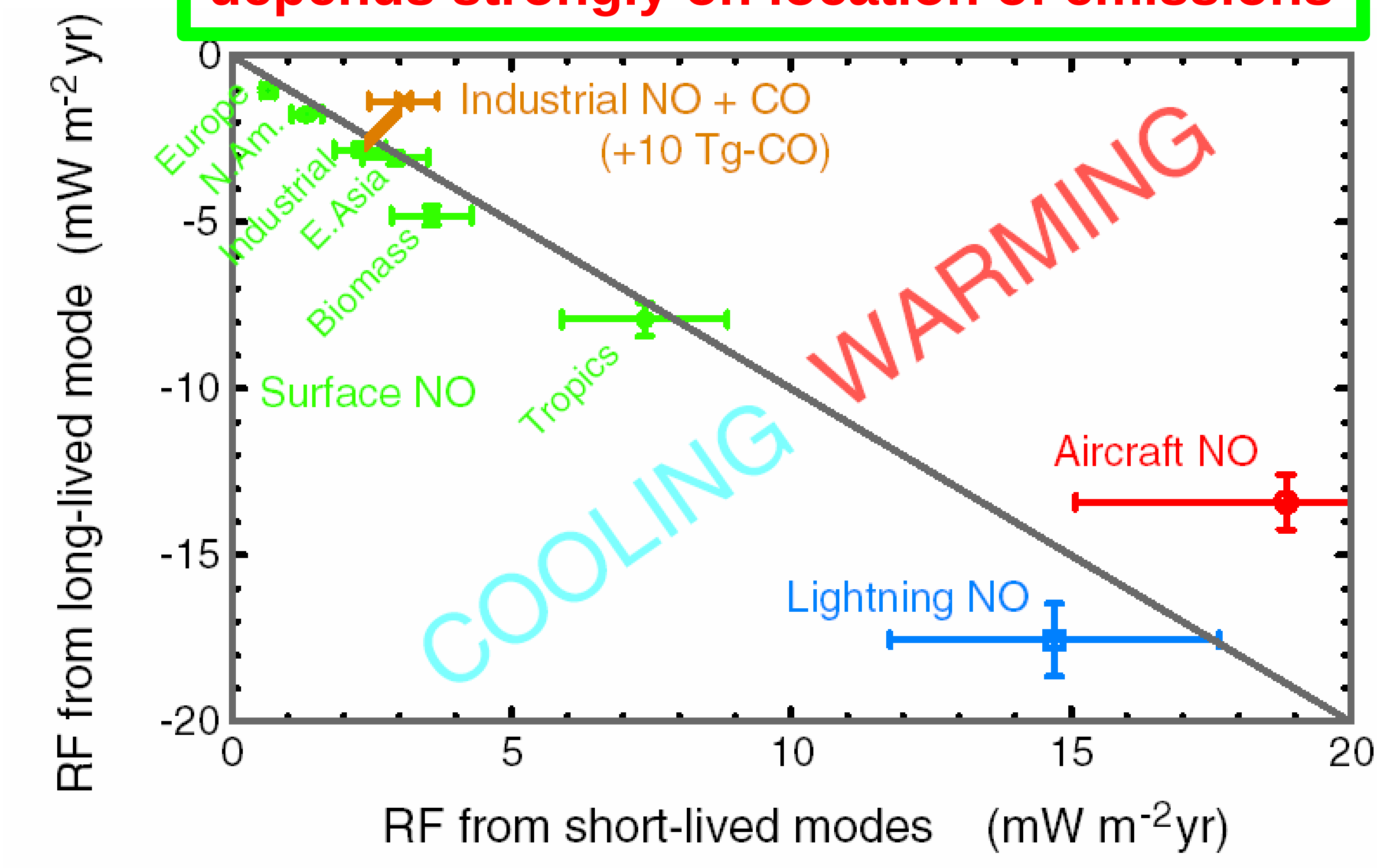
Integrated Radiative Forcing (CH4 & trop O3)
from 0.5 Tg-N as global fossil fuel
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
mW m-2 yr
Emissions
Period
0
10
20
30
40
50
Year of Run

NOx becomes an indirect greenhouse gas

0.5 Tg-N of NOx → short-lived trop-O_3 increase (warming)

→ long-lived CH_4 & O_3 decrease (cooling)

depends strongly on location of emissions



IPCC (2001) notes geographic shift in NOx emissions for SRES scenarios

Table 4.8: Estimates of the global tropospheric NO_x budget (in TgN/yr).

Anthropogenic emissions by continent/region	Y2000	Y2100(A2)
Africa	2.5	21.8
South America	1.4	10.8
Southeast Asia	1.2	6.8
India	1.7	10.0
North America	10.1	18.5
Europe	7.3	14.3
East Asia	5.6	24.1
Australia	0.5	1.1
Other	2.3	2.6
Sum	**32.6**	**110.0**

EDGAR-HYDE 1.3: HISTORICAL ANTHROPOGENIC EMISSIONS 1890-1990

This dataset comprises global anthropogenic emissions of CO_2, CH_4, N_2O, CO, NO_x, NMVOC, SO_2 and NH_3 for the period 1890 to 1990. With time steps of 10 year emissions have been made available both on an 1x1 degree grid (total of all sources) as well as for each of the 13 EDGAR 2.0 regions. If you use this dataset, please cite the dataset as mentioned below.

After completion of this dataset, EDGAR 3.2 data for 1990-1995 (1970-1995 for direct greenhouse gases) have become available with updated emissions and expanded source categories. To take account of these revised estimates for recent years, the original EDGAR-HYDE 1.3 dataset should be adjusted to the new EDGAR estimates for 1970 onwards: EDGAR-HYDE 1.4: Adjusted Regional Historical Emissions 1890-1990

.

Reference: Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M. and J. Lelieveld (2001) A 1 x 1 degree resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. *Global Biogeochemical Cycles*,15(4), 909-928.

Datasets

- Regional emissions for every 10 year are provided for ten source categories.
- Gridded emission inventories compiled for total anthropogenic emissions for every 10 year.

Parties to the UN FCCC are required to report National Greenhouse Gas Inventories

UNITED NATIONS

UNFCCC Framework Convention on Climate Change

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FCCC/CP/2002/8
28 March 2003

Original: ENGLISH

CONFERENCE OF THE PARTIES
Eighth session
New Delhi, 23 October – 1 November 2002
Agenda item 4 (b) (ii)

REVIEW OF THE IMPLEMENTATION OF COMMITMENTS AND OF OTHER PROVISIONS OF THE CONVENTION

NATIONAL COMMUNICATIONS: GREENHOUSE GAS INVENTORIES FROM PARTIES INCLUDED IN ANNEX I TO THE CONVENTION

UNFCCC guidelines on reporting and review

CONFERENCE OF THE PARTIES

Eighth session

New Delhi, 23 October – 1 November 2002

Estimates of emissions and removals

18. Article 12.1(a) of the Convention requires that each Party shall communicate to the COP, through the secretariat, inter alia, a national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. As a minimum requirement, inventories shall contain information on the following greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Annex I Parties should report anthropogenic emissions and removals of any other greenhouse gases whose 100-year global warming potential (GWP) values have been identified by the IPCC and adopted by the COP. Annex I Parties should also provide information on the following indirect greenhouse gases: carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOCs), as well as sulphur oxides (SOx).

Table 4.D - Agriculture

Fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3 and NOx

Fraction of livestock N excretion that volatilizes as NH_3 and NOx

Table 5 NGGI Reporting (July – December)

Please provide a separate report for each power station or section of power station using distinct technology and fuel.
Information is sought on the basis of Gross Calorific Value (Higher Heating Value), at constant pressure and "as fired".

Name of power statio n:	Combustion technology*:	Reporting for 6-month period: 1 July 20__ to 31 December 20__

	Fuel type*	Fuel use (PJ)	Specific energy content of fuel (GJ/t or specify units)	Carbon oxidation factor* (COF) (%)	Fuel emission factors						
					CO_2* (Gg/PJ)	CH_4* (Mg/PJ)	N_2O* (Mg/PJ)	NO_x* (Mg/PJ)	CO* (Mg/PJ)	NMVOC* (Mg/PJ)	SO_2 (Mg/PJ)
Primary fuel											
Secondary fuel											
Other fuel											

* Denotes data that will be made publicly available.

Notes for completing table:

Combustion technology	
PW	Pulverised wall (coal)
TF	Tangentially fired
PFBC	Pressurised fluidised bed combustor
IGCC	Integrated gasification combined cycle (coal)
CC	Combined cycle (NG)
IC	Internal combustion
GT	Gas turbine
B	Boiler
/C	Cogeneration (in combination with other combustion technology)

Unit conversion

Mg = Megagrams = 10^6 grams
Gg = Gigagrams = 10^9 grams
PJ = Petajoules = 10^{15} joules

Fuel type	
BC	Black Coal
BrC	Brown Coal
BQ	Briquettes (brown coal)
FO	Fuel oil
DO	Distillate
NG	Natural gas
CSG	Coal seam gas
BAG	Bagasse
W	Wood or wood waste
BM	Biomass (other)
LFG	Landfill gas
BG	Biogas (other)
MSW	Municipal solid waste
LW	Liquid waste

Carbon oxidation factor (COF)

Proportion (%) of carbon in fuel that is oxidised to CO_2 during combustion. Factor accounts for carbon stored in solids such as ash and soot arising from incomplete combustion of carbon in fuel. For example, a 99% oxidation factor indicates that 99% of carbon in the fuel is oxidised during combustion and 1% remains as soot etc.

CO_2 emission factor

Emission factor should be separate from the oxidation factor, so that: CO_2 emissions = fuel use (PJ) × carbon oxidation factor × CO_2 emission factor. If CO_2 emission factor is calculated from analysis that already accounts for unburnt carbon, then please report carbon oxidation factor as 100%.

Default emission factors It is preferable to obtain actual emission factors. However, if an emission factor is not known, then use the default factors below obtained from the NGGI Workbook for Fuel Combustion 1.1, 1996.

Combustion technology	Fuel type	COF (%)	CH_4 (Mg/PJ)	N_2O (Mg/PJ)	NO_x (Mg/PJ)	CO (Mg/PJ)	NMVOC (Mg/PJ)	SO_2[a] (Mg/PJ)
B	NG	99.5	0.1	0.1	226	16	0.6	2.3
B	FO	99	0.8	0.6	186	14	2.1	1282.1
B	DO	99	0.04	0.6	64	13	1.4	57
TF	BC	99	0.9	0.8	306	11	1.7	370
PW	BC	99	0.9	0.8	462	11	1.7	370
TF	BrC	99	0.9	1.4	136	17	1.7	150
GT	NG	99.5	8.0	0.1	190	46	2.4	2.3
IC	NG	99.5	240	0.1	1331	340	80	2.3
IC	FO	99	4.0	0.6	1322	349	45	1282.1
IC	DO	99	4.0	0.6	1322	349	45	57
B	BAG	98	10	4.1	84	1625	16.3	0
B	W	98	4.2	4.1	75	680	6.8	0
IC	BG/LFG	99.5	240	0.1	1331	340	80	2.3

(a) SO_2 emissions factors from 2000 NGGI, based on sulphur content of fuel.

United Nations Economic Commission for Europe – data source

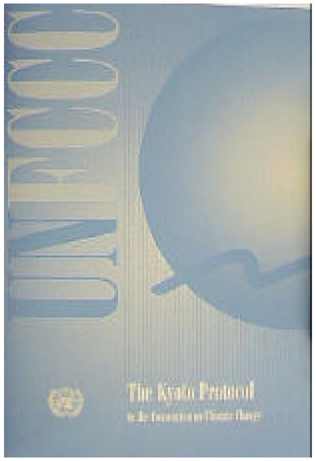
Table 2. Anthropogenic emissions of nitrogen oxides (1980-2010) in the ECE region (September 2000)
(thousands of tonnes NO2 per year)

Party/Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	2005	2010
Armenia		15	17	16	15	44	53	51	55	51	46	40	21	12	11	14	11	15	10		
Austria	228	220	218	215	215	217	213	209	202	194	193	196	187	175	182	170	170	171	169	154	107
Belarus	234	235	235	237	240	238	258	263	262	263	285	281	224	207	203	195	172	188	164	184	180
Belgium [4]	442					325	317	338	345	357	339	335	343	341	342	336	316	306	301		181
Bosnia and Herzegovina																					
Bulgaria								416	415	411	361	266	239	242	230	266	259	225	223	270	266
Canada [5]	1959	1907	1897	1884	1871	2038	2043	2131	2204	2188	2104	2003	1997	2006	2026	2032	2011	2068	2051	2057	2085
Croatia [6]	60										87	65	56	59	65	65	68	73	76	83	87
Cyprus						14	16	16	18	19	18	16	19	19	20	19	21	21	22	23	23
Czech Republic 7	937	819	818	830	844	831	826	816	858	920	742	725	698	574	435	412	432	423	413	310	286
Denmark	273	243	264	257	270	298	319	313	303	285	279	322	276	275	266	248	288	248	231	159	133
Estonia								70	70	69	68	63	39	38	41	42	44	45	46		
Finland [4]	295	276	271	261	257	275	277	288	293	301	300	290	284	282	282	258	268	260	252	224	224
France [2)4)7)]	2030	1927	1885	1860	1853	1827	1786	1816	1819	1867	1877	1942	1880	1769	1739	1714	1695	1643	1652	1200	860
FYR Macedonia 1																		6 [a]			
Georgia	121	125	130	137	137	140	133	134	134	130	129	112	47	32	20	26	49	54			
Germany [8)9)]	3334	3259	3219	3258	3305	3276	3286	3327	3208	2989	2709	2501	2311	2198	2042	1989	1919	1846	1780	2130	1081 [b]
Greece [3]						306					326	333	334	331	342	341	378	361	382		344
Hungary [4]	273	270	268	266	264	262	264	265	258	246	238	203	183	184	188	190	196	200	217	210	198

What Greenhouse Agents are listed under Kyoto ?

Annex A

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)



What are also included in the NGGI reporting req's ?

National Inventory for Annex I Parties

- Sulfur dioxide (SO_2)
- Carbon monoxide (CO)
- Nitrogen Oxides (NO_X)
- Non-methane VOC
- ?Ammonia (NH_3)

What Anthropogenic Greenhouse Agents are forgotten by the UNFCCC ?

CFCs & HCFCs *(Montreal - OK)*

Black Carbon

Organic Carbon Aerosols

Dust

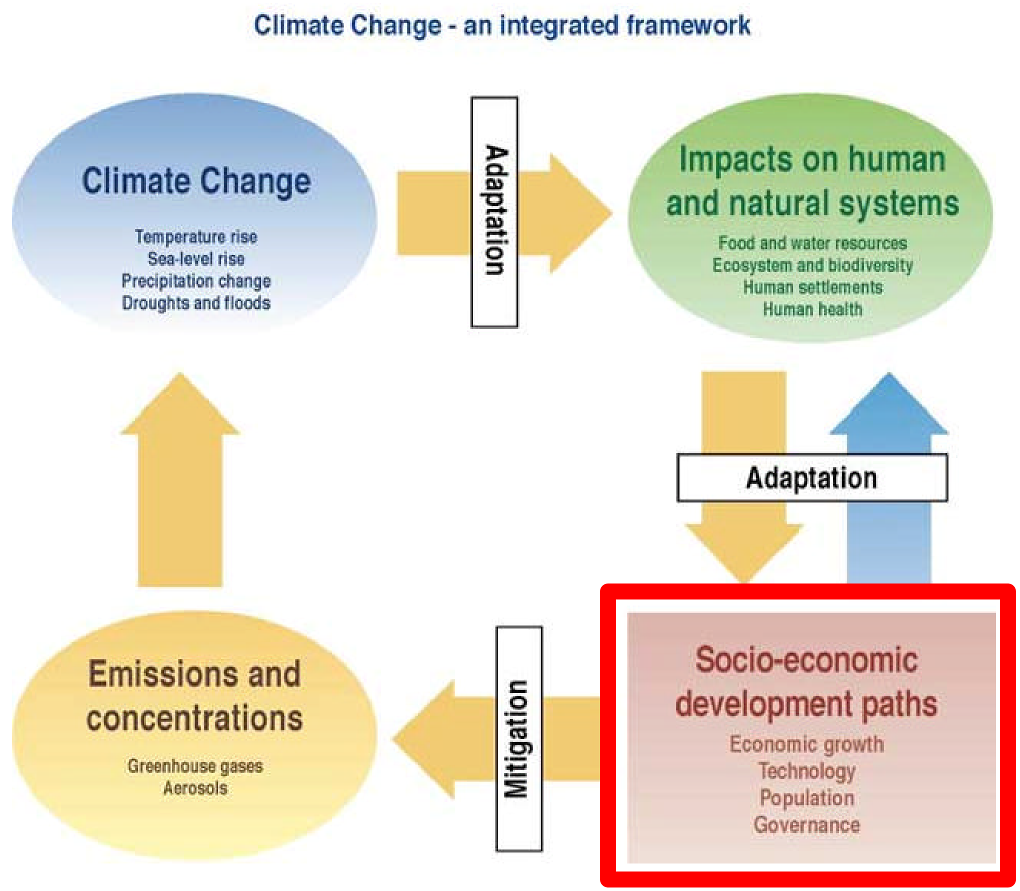
Which Greenhouse Agents have a good historical record ?

✓ CO_2	✓ sulfate
✓ CH_4	☒ fossil fuel OC/BC
✓ N_2O	☒ biomass OC/BC
✓ CFCs	☒ mineral dust
✓ solar	☒ aerosol indirect
✓ strat O_3	☒ land use /albedo
☒ trop O_3	

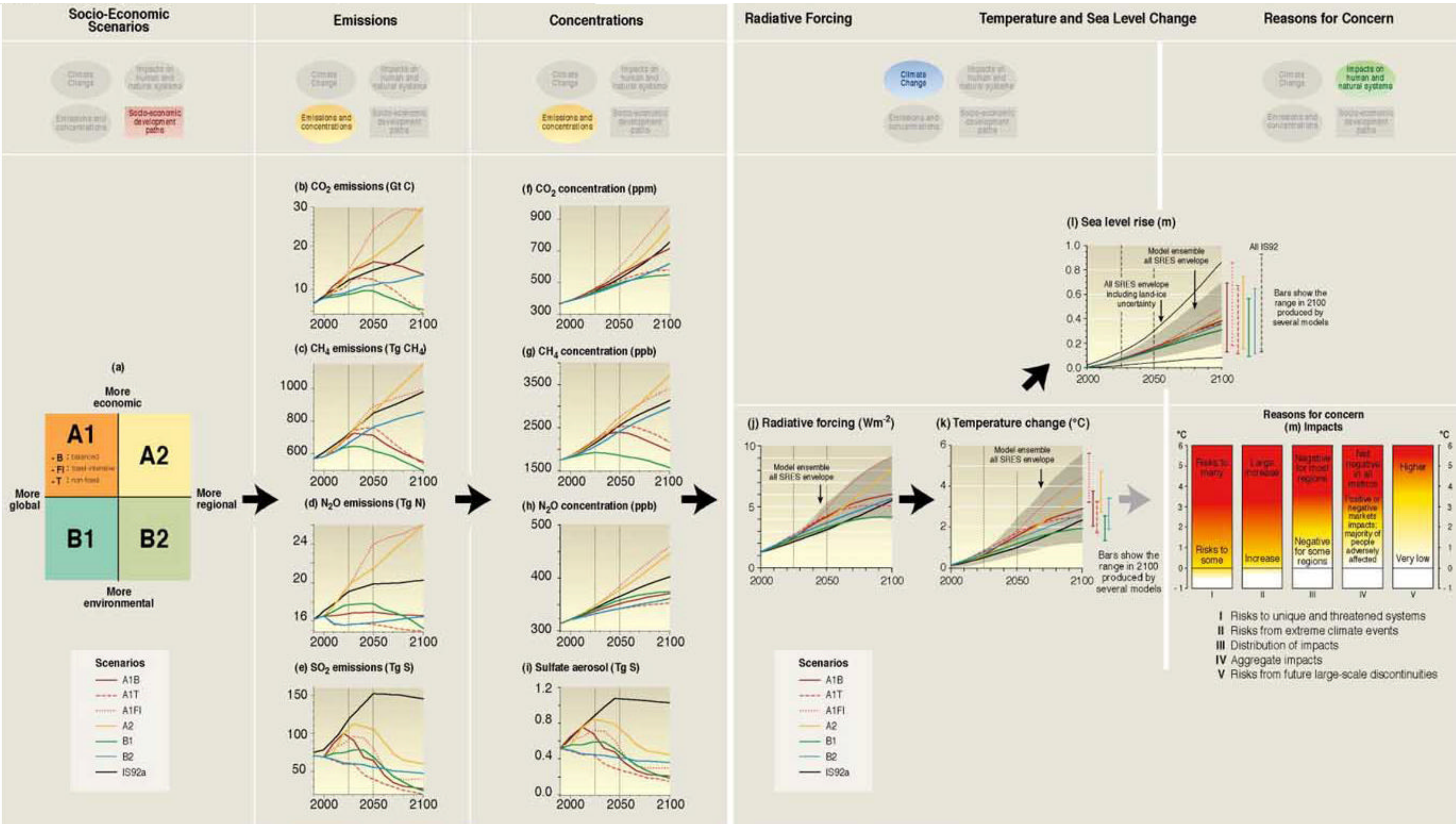
Which Greenhouse Agents are attributable ?

Climate Change involves the entire Earth system including ecosystems and human dimensions

The 21st Century - Where does the SRES come from?



IPCC SRES Scenarios for the TAR



A1FI, A1T and A1B

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity-building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1 B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvment rates apply to all energy supply and end use technologies).

A2

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

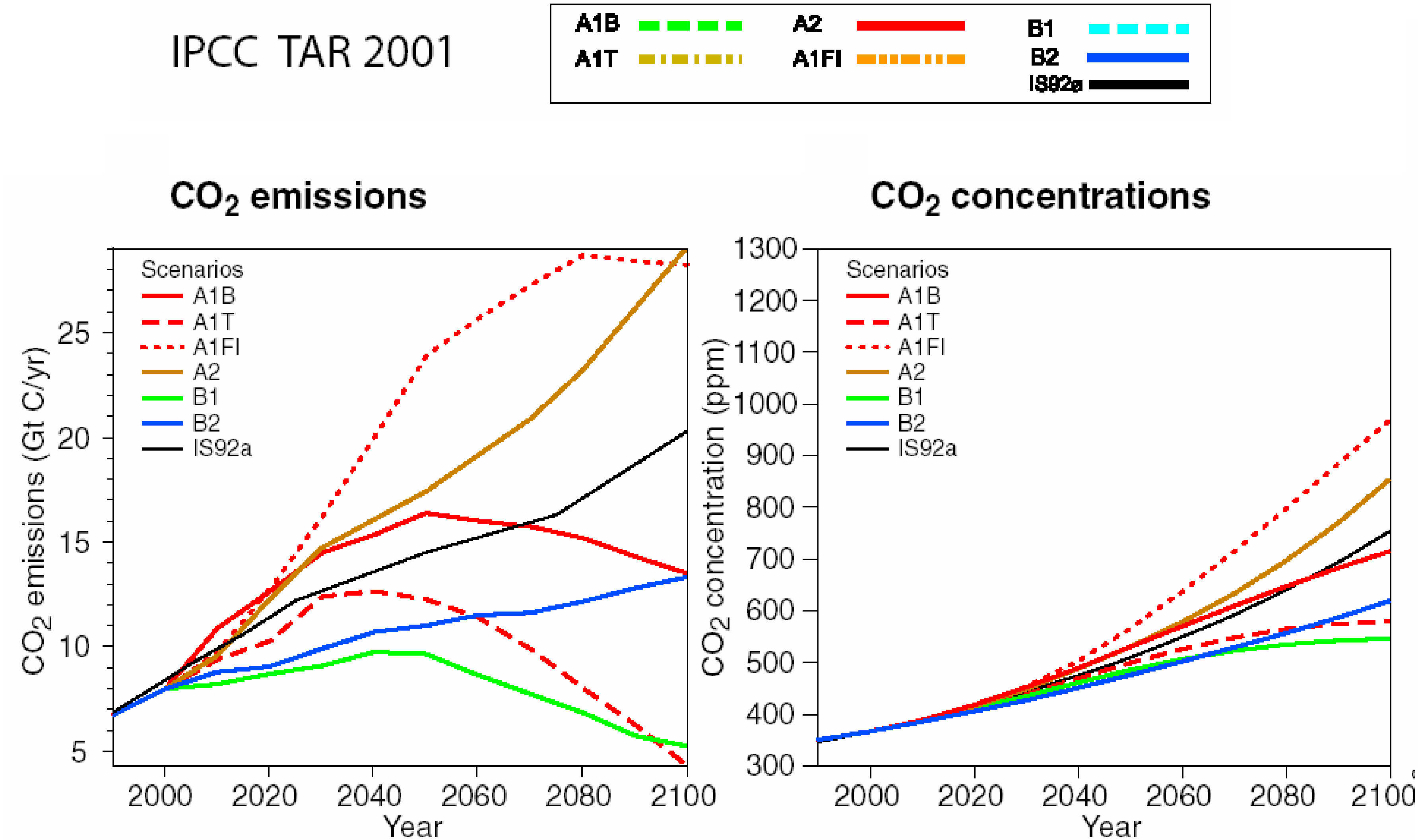
B1

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

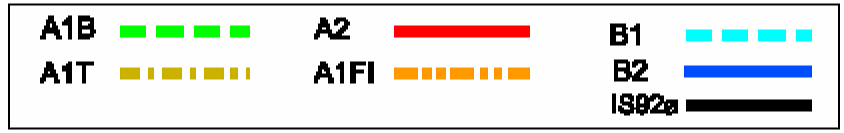
B2

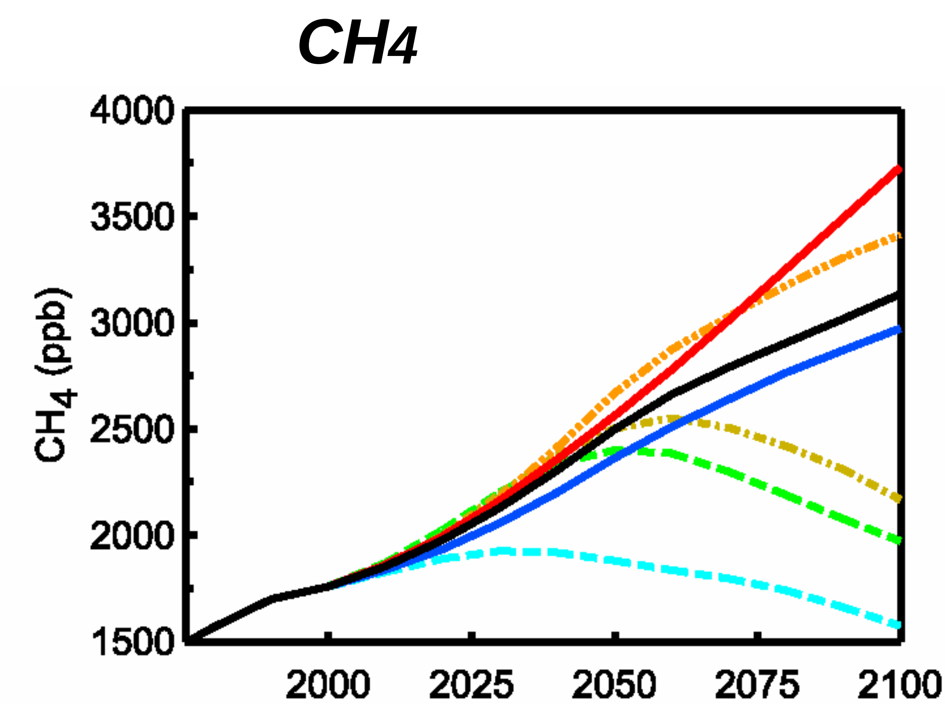
The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

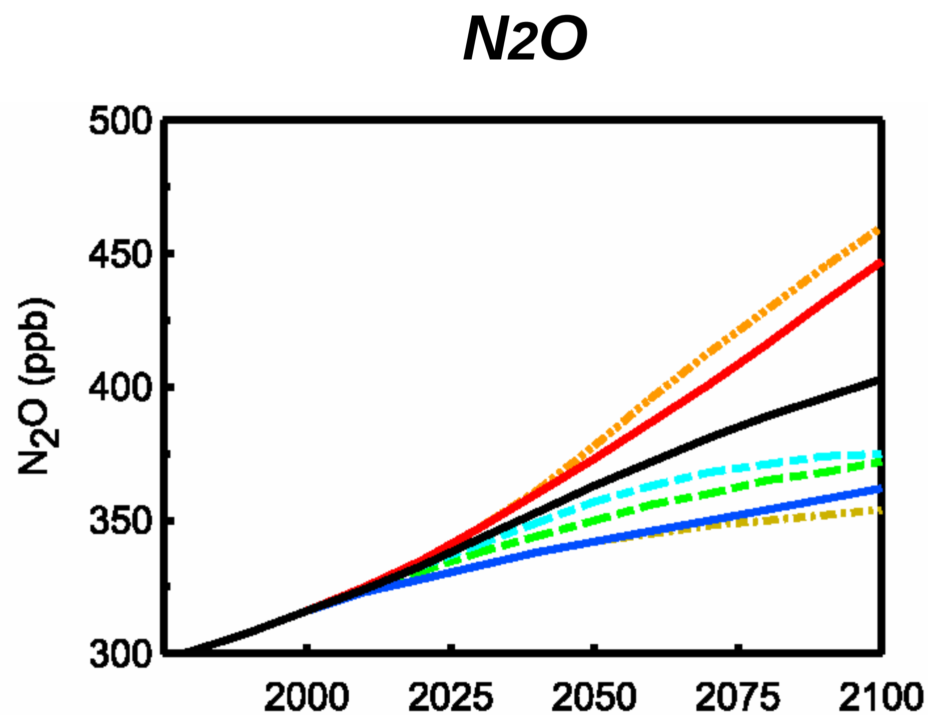
IPCC TAR 2001



IPCC TAR 2001







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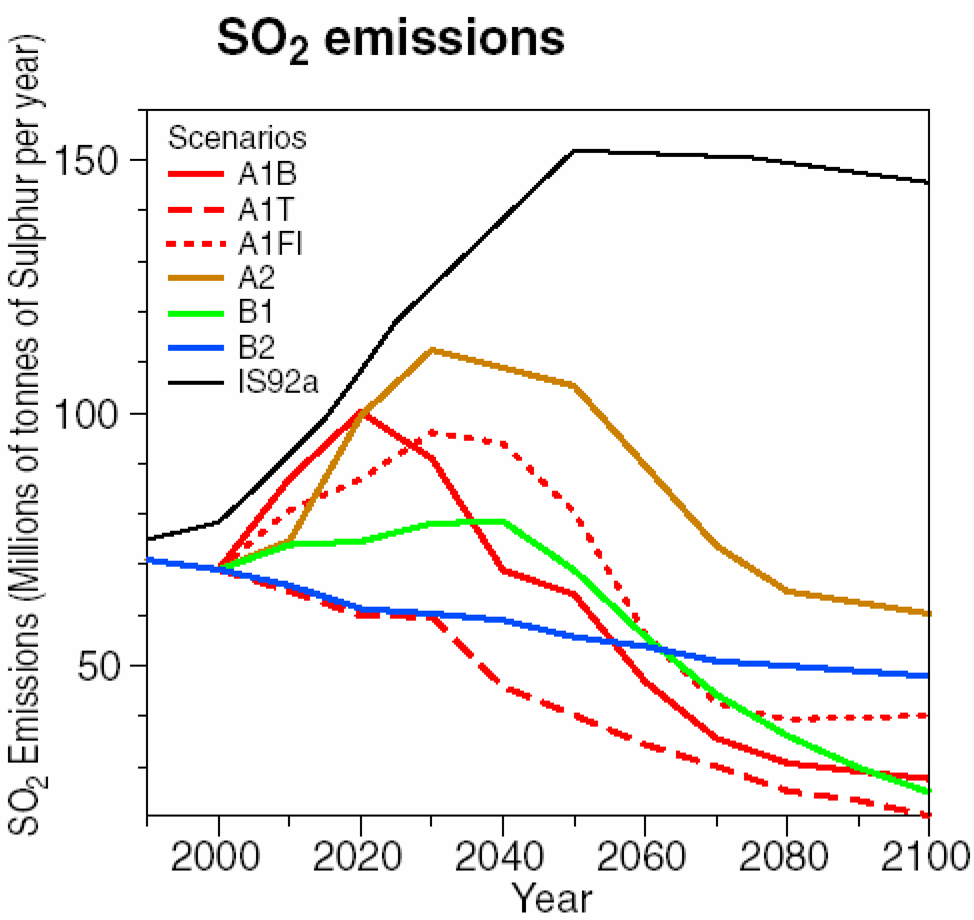

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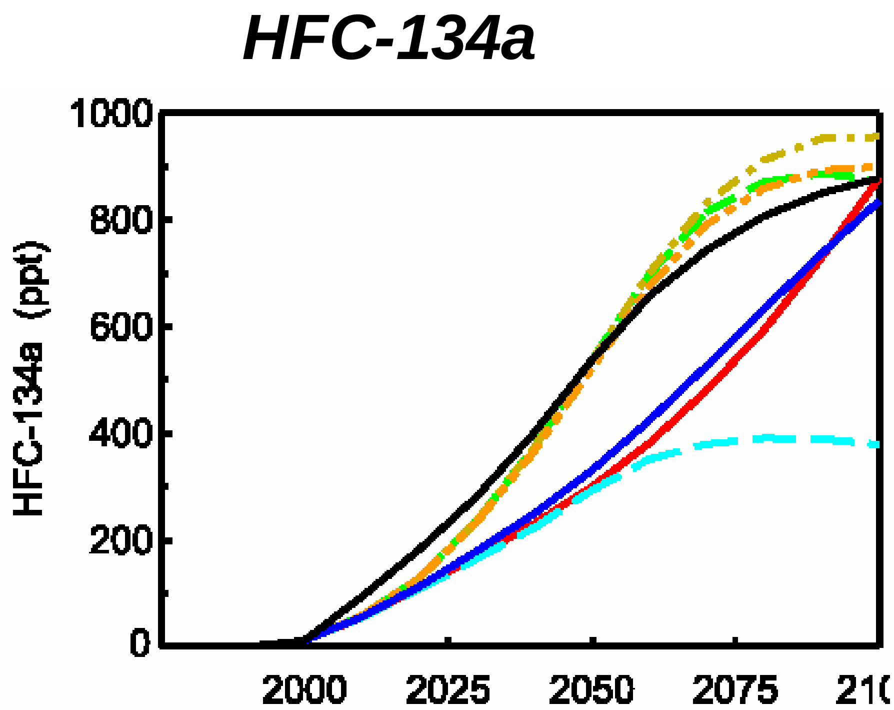

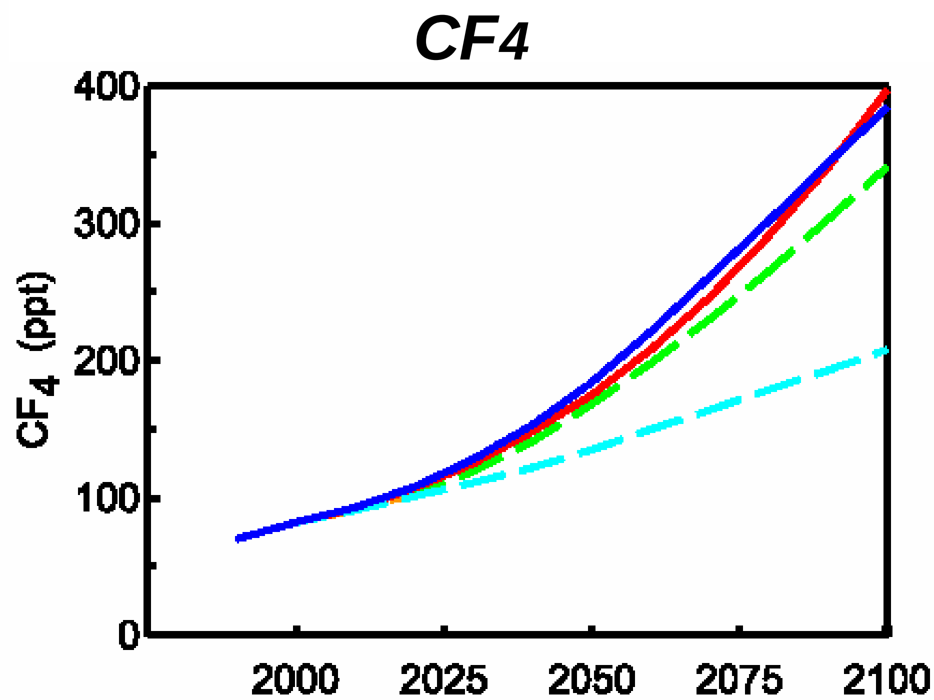

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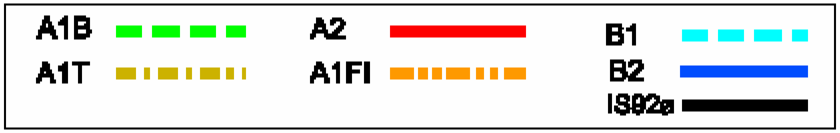
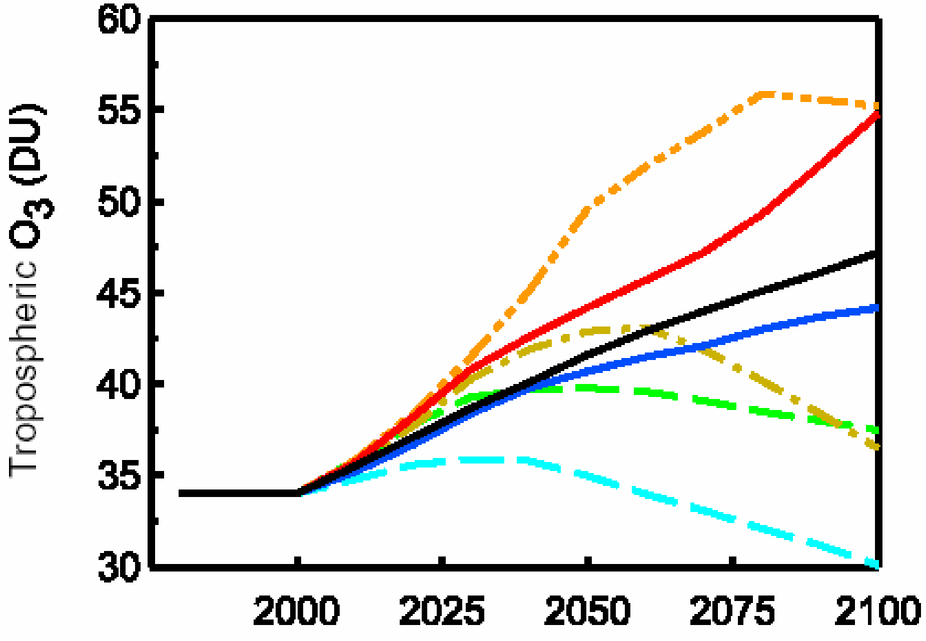
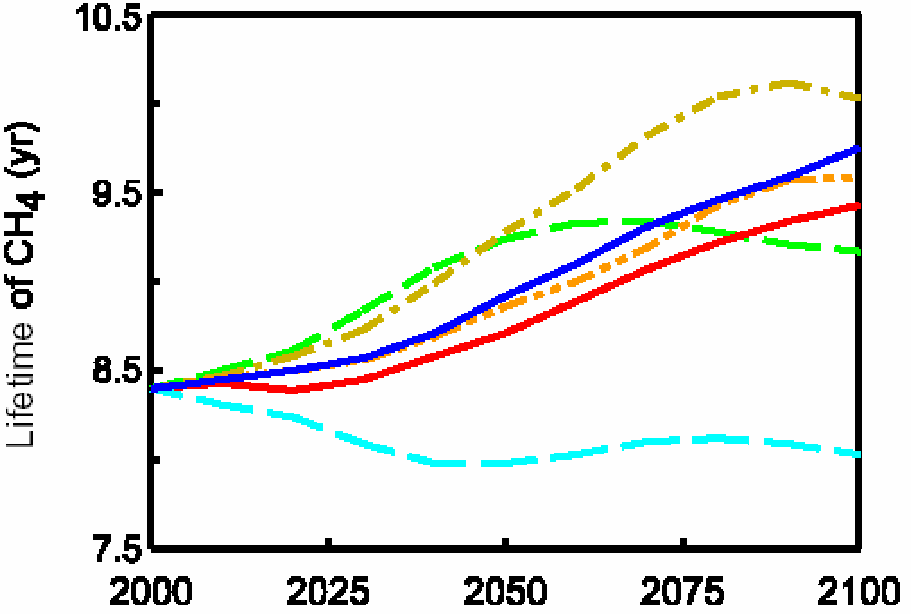
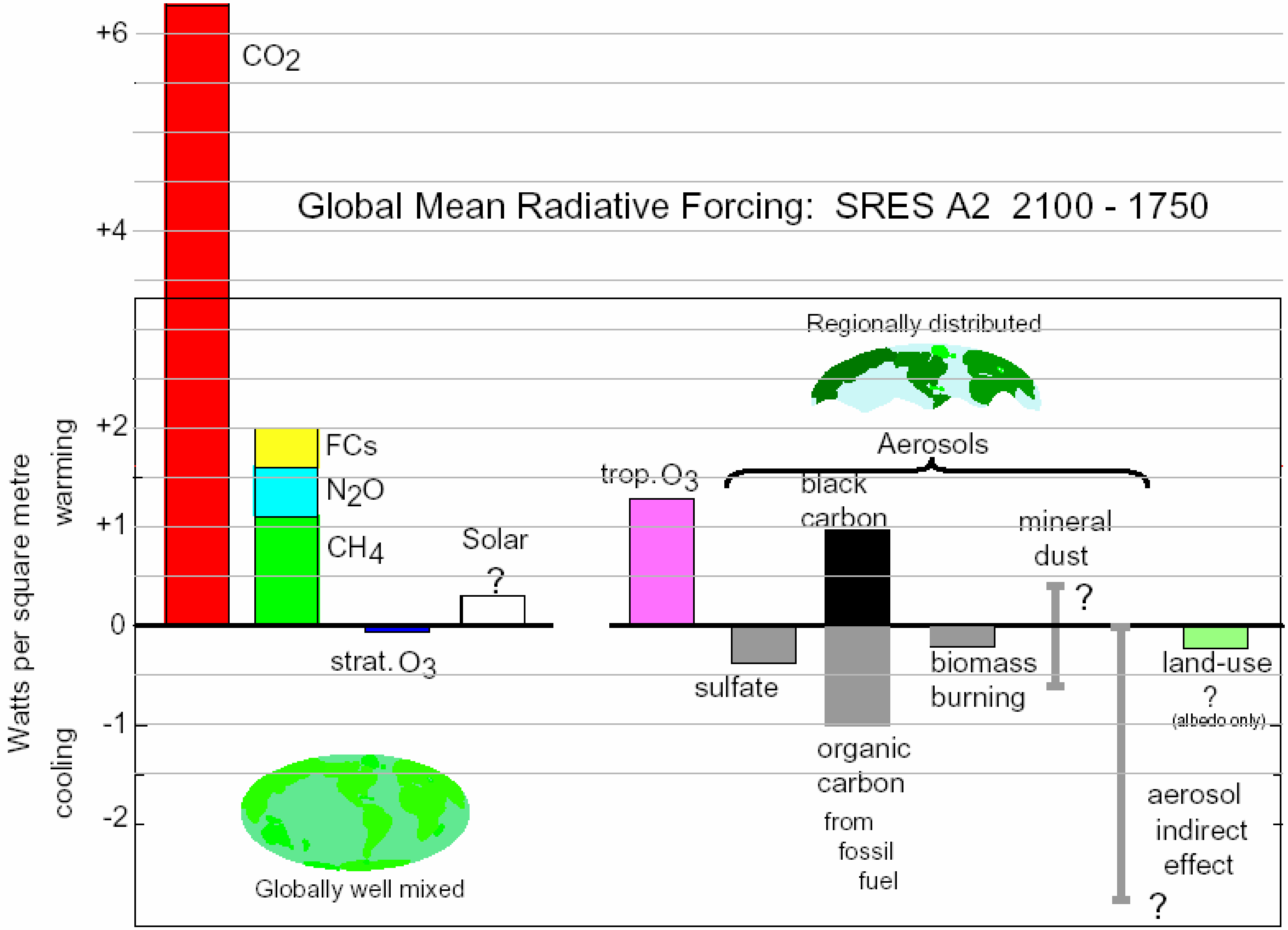


tropospheric O3

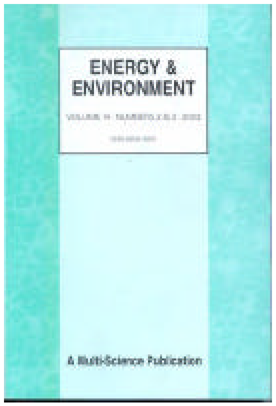


lifetime of CH4




Global Mean Radiative Forcing: SRES A2 2100 - 1750
Watts per square metre
warming
cooling
+6
+4
+2
+1
0
-1
-2
CO2
FCs
N2O
CH4
strat. O3
Solar
?
Globally well mixed
Regionally distributed
trop. O3
Aerosols
black carbon
mineral dust
?
sulfate
biomass burning
land-use
?
(albedo only)
organic carbon
from fossil fuel
aerosol indirect effect
?

IPCC SRES under attack from the political side



(*Vol.14, No 2 & 3, 2003*, pp.187-214)

IPCC SRES REVISITED: A RESPONSE[1]

Nebojsa Nakicenovic, Arnulf Grübler, Stuard Gaffin, Tae Tong Jung, Tom Kram, Tsuneyuki Morita, Hugh Pitcher, Keywan Riahi, Michael Schlesinger, P. R. Shukla, Detlef van Vuuren, Ged Davis, Laurie Michaelis, Rob Swart and Nadja Victor

ACKNOWLEDGEMENTS:
We thank Vadim Chirkov, Erik Slentoe, and Jayant Sathaye for their assistance and comments.

ABSTRACT

Mr. Castles and Mr. Henderson have criticized the Special Report on Emissions Scenarios (SRES) and other aspects of IPCC assessments. It is claimed that the methodology is "technically unsound" because market exchange rates (MER) are used instead of purchasing power parities (PPP) and that the scenarios themselves are flawed because the GDP growth in the developing regions is too high.

IPCC SRES under attack from the science side

<u>The "alternative" scenario</u> is an extension of the scenario we defined for 2000-2050 (reference 6), with the annual CO_2 growth decreasing linearly to zero between 2050 and 2100 such that atmospheric CO_2 stops growing by 2100. Such an assumption, which is required for any scenario that achieves stabilization, implies at least a 50% reduction in fossil fuel use or CO_2 capture and sequestration.

J.E. Hansen et al., 2003

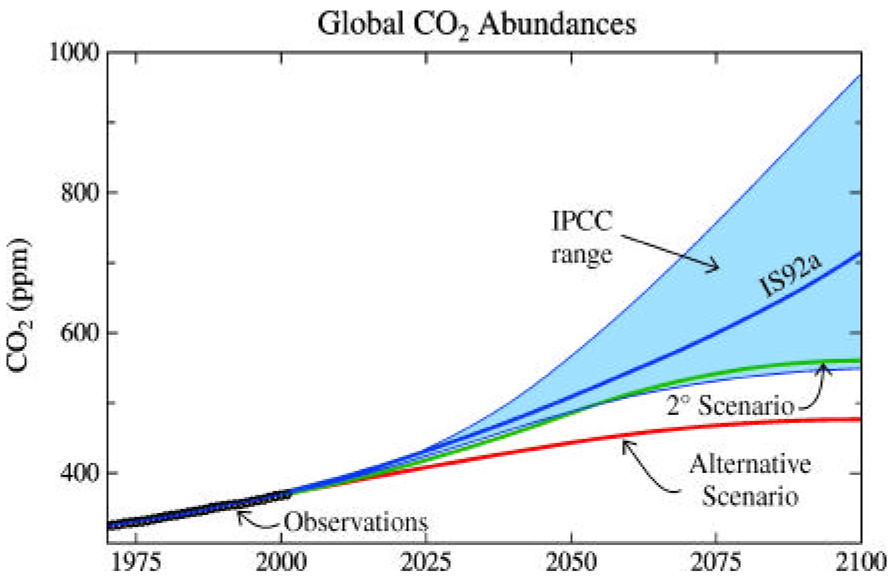
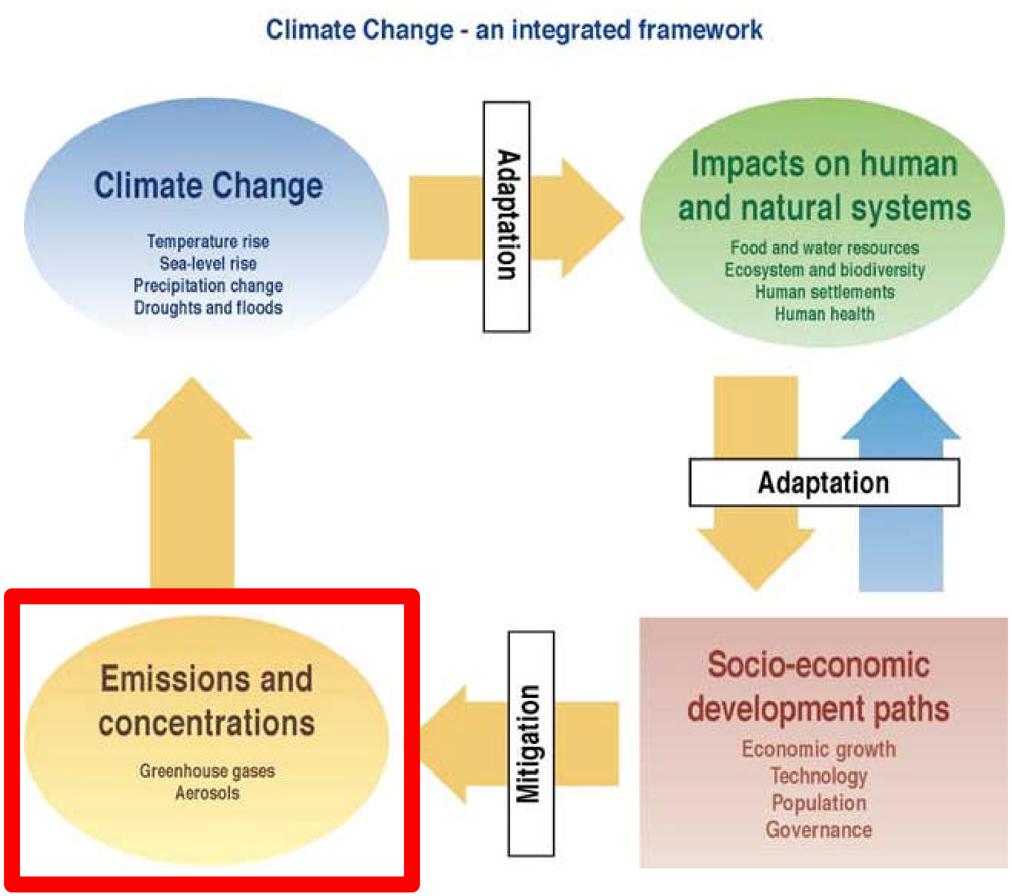
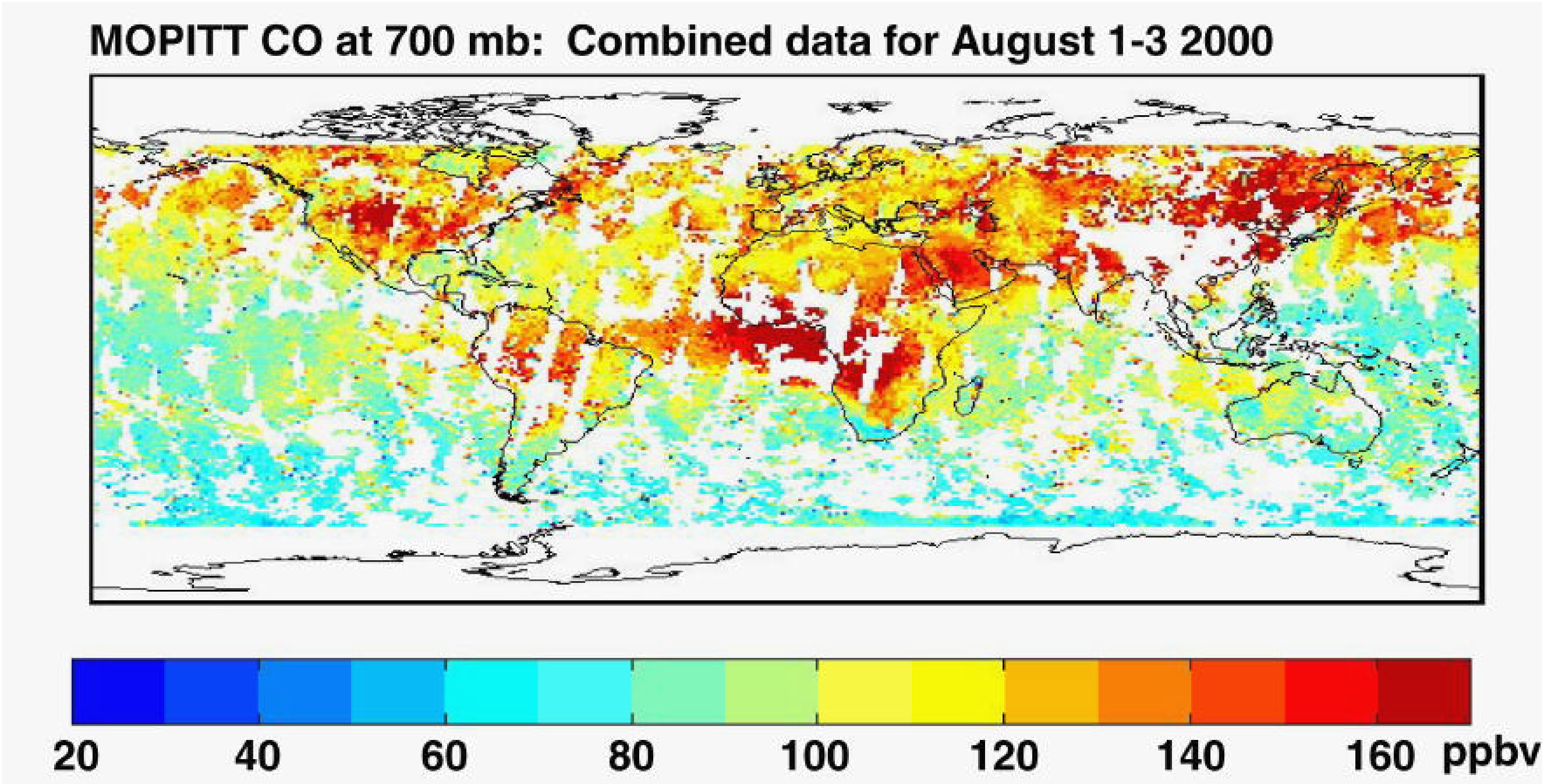


Figure 14. CO_2 in IPCC (2001), "alternative" and "2° C" scenarios. In the alternative scenario ΔCO_2 decreases linearly from 1.7 ppm/year in 2000 to 1.3 ppm/year in 2050 and then linearly to zero in 2100; CO_2 peaks at ~475 ppm in 2100. In the "2°C" scenario ΔCO_2 increases linearly from 1.7 ppm/year in 2000 to 3 ppm/yr in 2050 and then decreases linearly to zero in 2100; CO_2 peaks at ~560 ppm in 2100. Upper and lower limits of IPCC range are their scenarios A1FI and B1 [IPCC, 2001, Appendix II, p. 807 and Figure 18, p.65].

Satellite Observations can provide the necessary global validation of current emissions.




MOPITT CO at 700 mb: Combined data for August 1-3 2000
20
40
60
80
100
120
140
160
ppbv

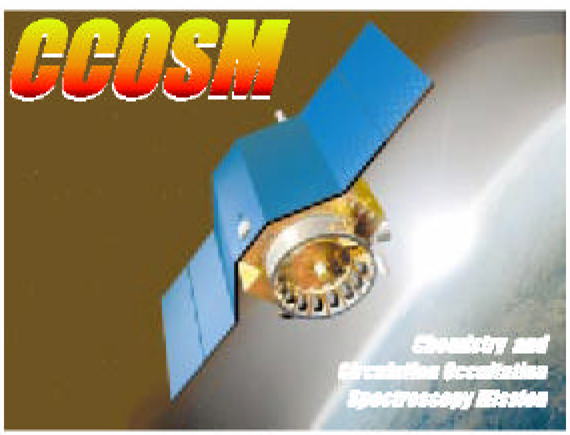
GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 24, PAGES 4571-4574, DECEMBER 15, 2001

CO_2 source inversions using satellite observations of the upper troposphere

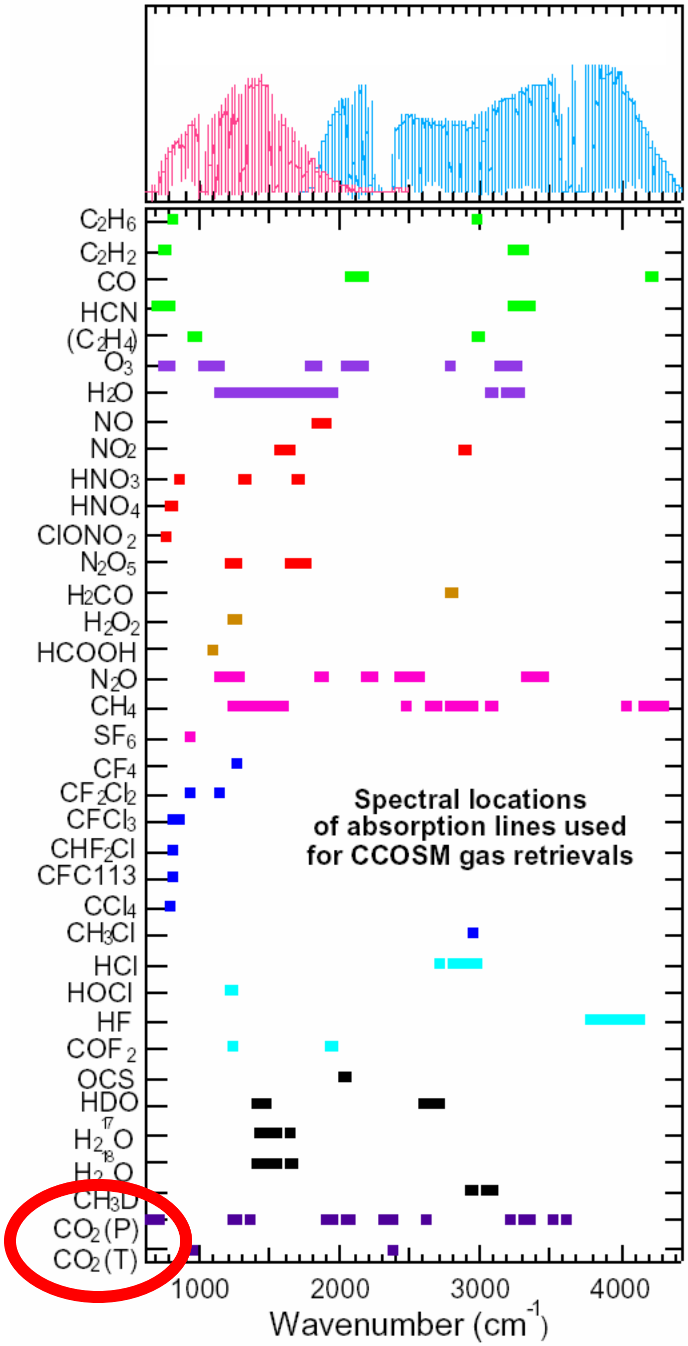
Bernard C. Pak and Michael J. Prather

Department of Earth System Science, University of California, Irvine

Abstract. Satellite observations of CO_2 abundance in the upper troposphere can provide a major constraint for deriving the net carbon fluxes from tropical landmasses that is unavailable from current surface observations. Such global CO_2 profiling with an uncertainty of about 1% (3 ppm) contains key longitudinal information needed to derive surface fluxes in a standard Bayesian inversion. Upper-tropospheric data available from flight-proven FTIR solar occultation measurements could provide comparable information to that from yet-to-be-demonstrated column CO_2 observations, which have heretofore been the focus of carbon cycle studies. A strategy for improving CO_2 source inversions with either type of satellite data should focus on tropical observations and on careful evaluation of possible sampling biases affecting the observational uncertainties.

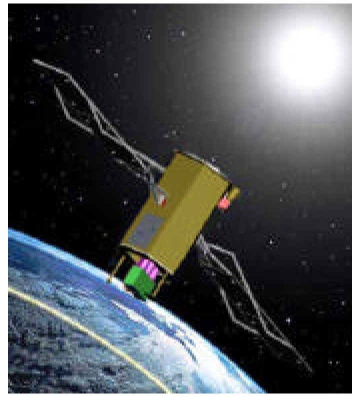


Chemistry and
Circulation
Occultation
Spectroscopy
Mission



Orbiting
Carbon
Observatory

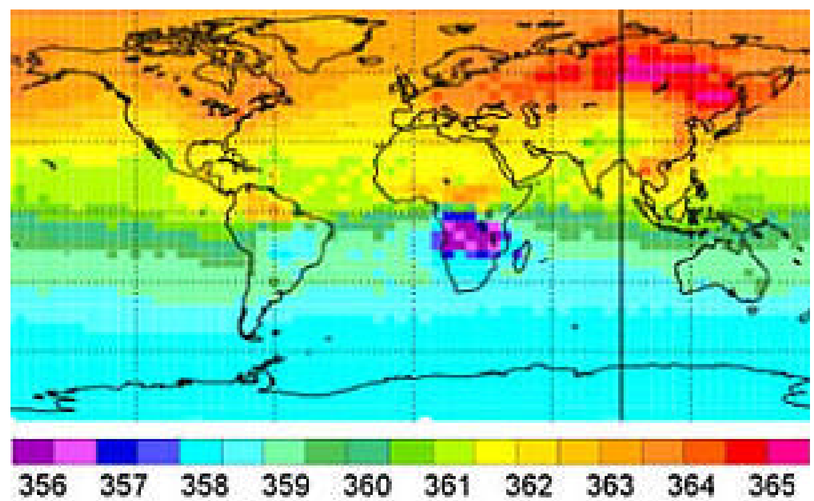
D. Crisp
JPL

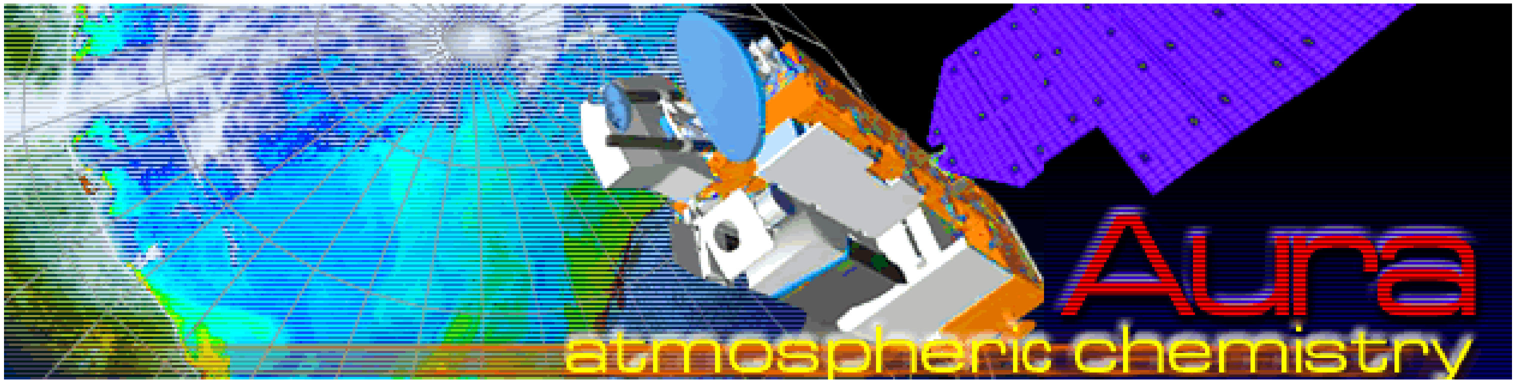


The Orbiting Carbon Observatory (OCO) provides space-based observations of atmospheric carbon dioxide (CO_2), the principal anthropogenic driver of climate change. This mission uses mature technologies to address NASA's highest priority carbon cycle measurement requirement. OCO generates the knowledge needed to improve projections of future atmospheric CO_2.

- Make the first, global, space-based observations of the column integrated CO2 dry air mole fraction, X_{CO2}
- Provide independent data validation approaches to ensure high accuracy (1 ppm, 0.3%)

simulated column-mean CO2



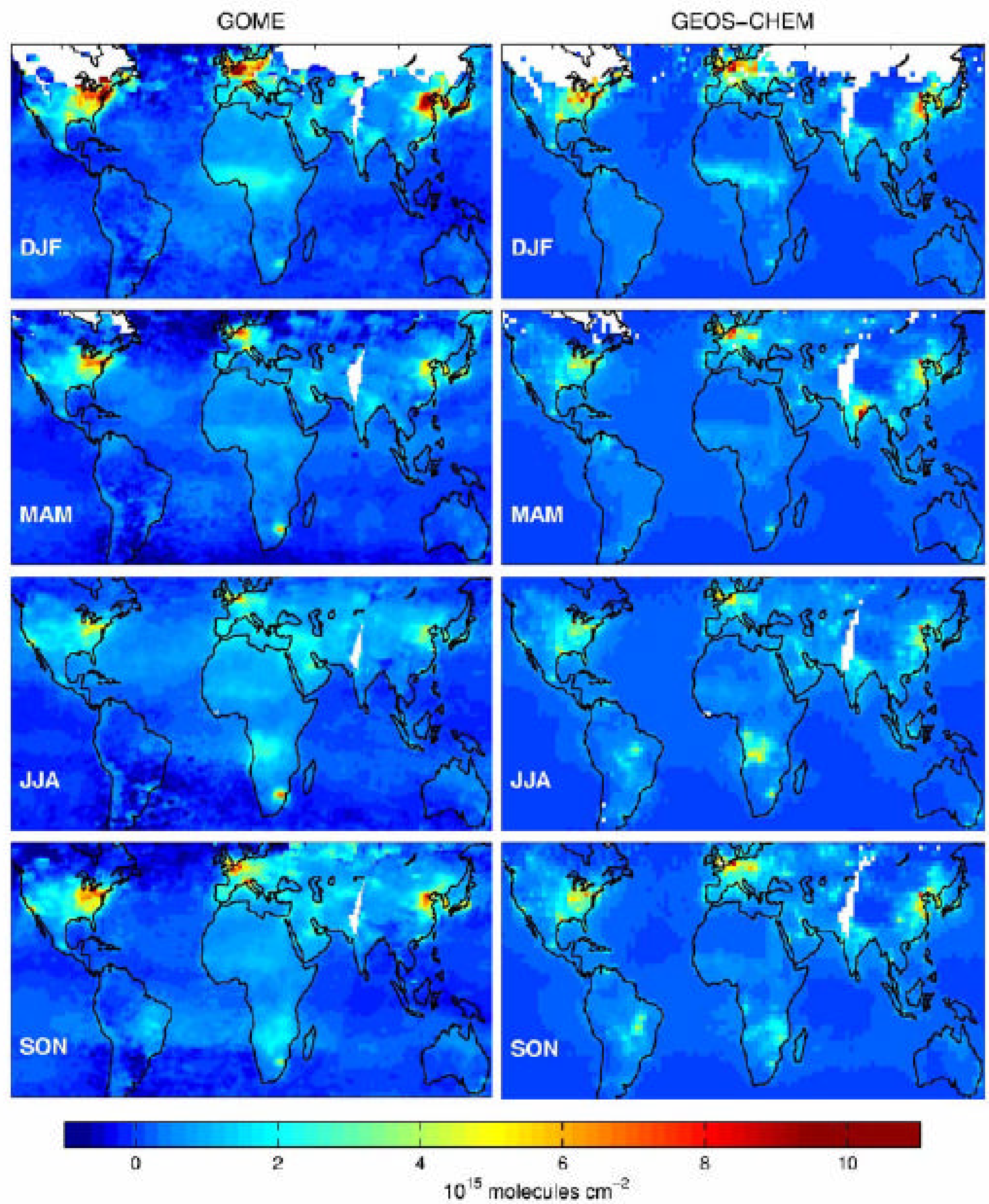


TES	**– tropospheric** O_3**,** CH_4**, CO,** HNO_3**, NO,** NO_2**,**
MLS	– upper trop / strat
HIRDLS	– upper trop / strat
OMI	– O_3

Seasonal mean tropospheric NO_2 columns for September 1996 – August 1997.

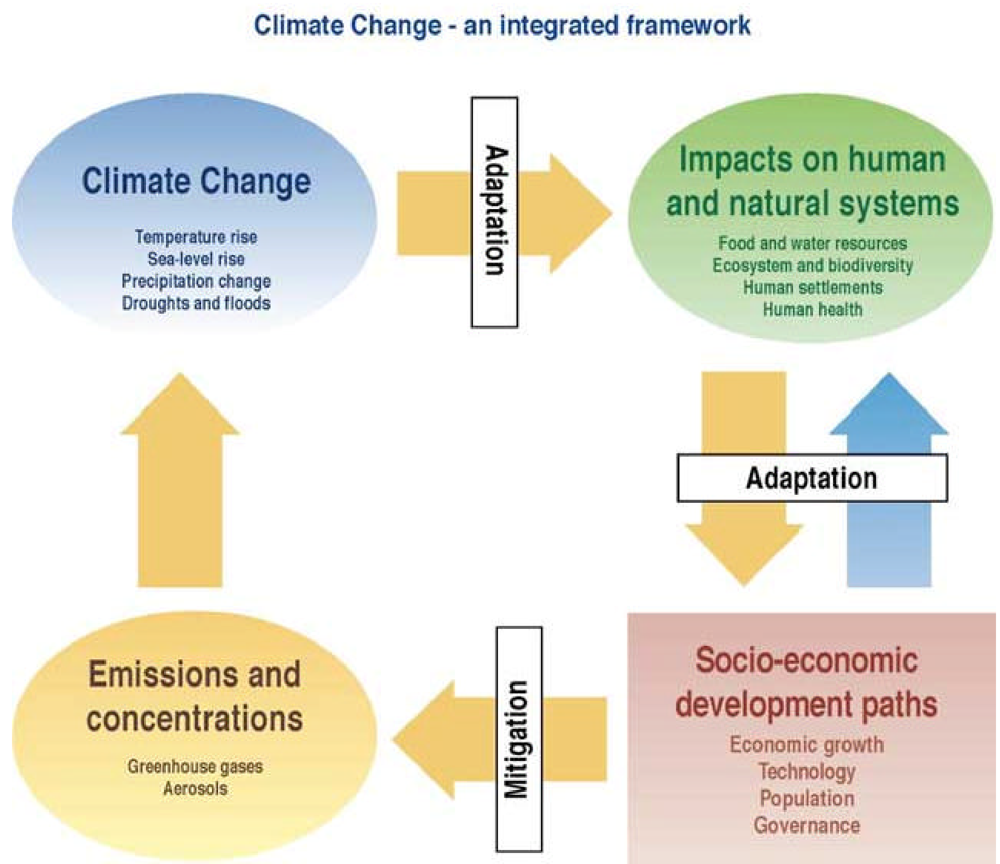
Monitoring surface NO emissions:

Global Inventory of Nitrogen Oxide Emissions Constrained by Space-based (GOME) Observations of NO2 Columns, *R.V. Martin et al., JGR, 2003.*



Feedbacks and Cross-Linkages

from Global Air Quality
to an H_2 economy

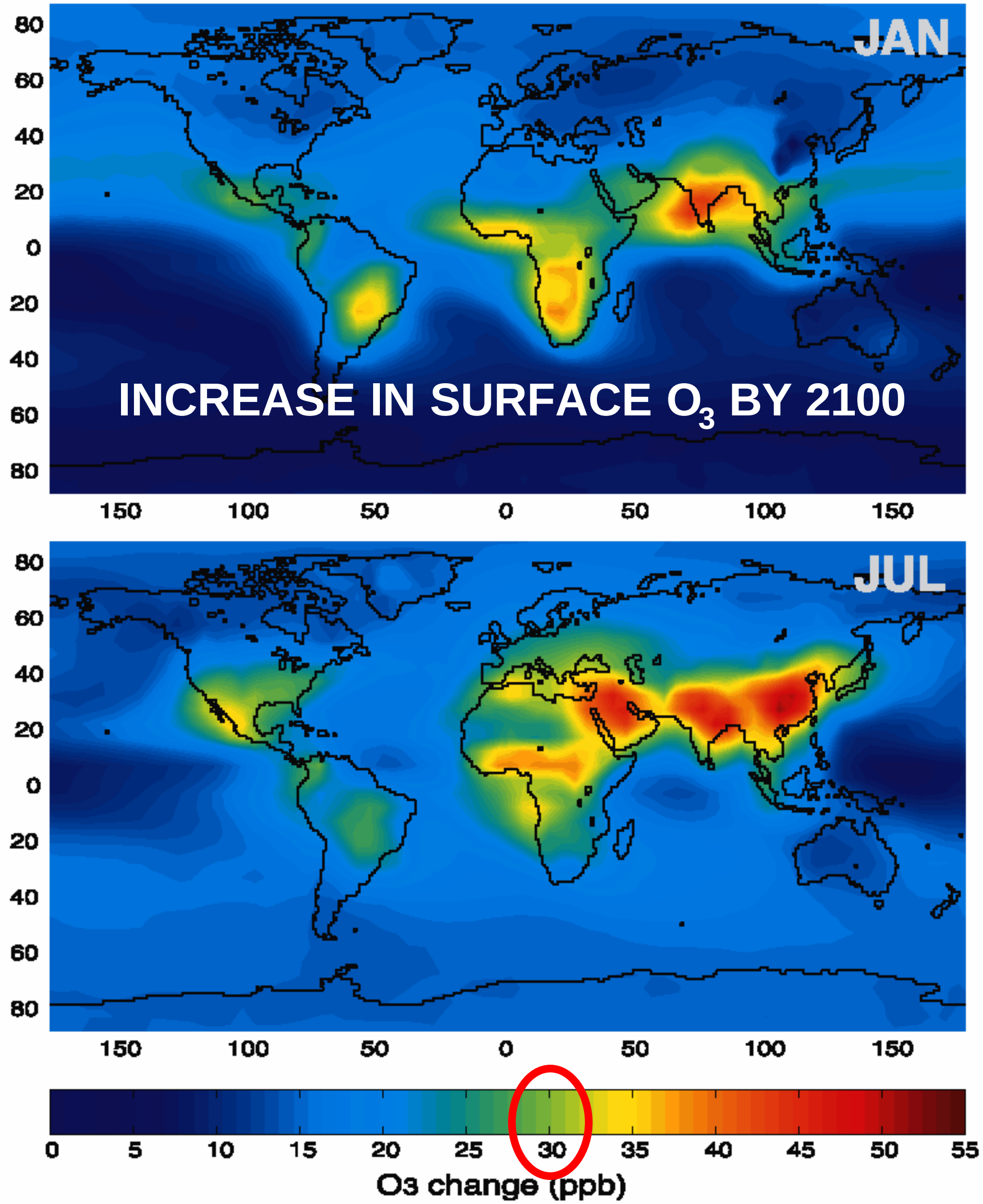


GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 2, 1100, doi:10.1029/2002GL016285, 2003

Fresh air in the 21st century?

Michael Prather,[1] Michael Gauss,[2] Terje Berntsen,[2] Ivar Isaksen,[2] Jostein Sundet,[2] Isabelle Bey,[3] Guy Brasseur,[4] Frank Dentener,[5] Richard Derwent,[6] David Stevenson,[6] Lee Grenfell,[7] Didier Hauglustaine,[8] Larry Horowitz,[9] Daniel Jacob,[10] Loretta Mickley, Mark Lawrence,[11] Rolf von Kuhlmann,[11] Jean-Francois Muller,[12] Giovanni Pitari,[13] Helen Rogers,[14] Matthew Johnson,[14] John Pyle,[14] Kathy Law,[14] Michiel van Weele,[15] and Oliver Wild[16]

IPCC (2001). "Changes projected in the SRES A2 and A1FI scenarios would degrade air quality over much of the globe by increasing background levels of O_3. In northern mid-latitudes during summer, the zonal average increases near the surface are about 30 ppb or more, raising background levels to nearly 80 ppb, threatening attainment of air quality standards over most metropolitan and even rural regions, and compromising crop and forest productivity. This problem reaches across continental boundaries since emissions of NOx influence photochemistry on a hemispheric scale."



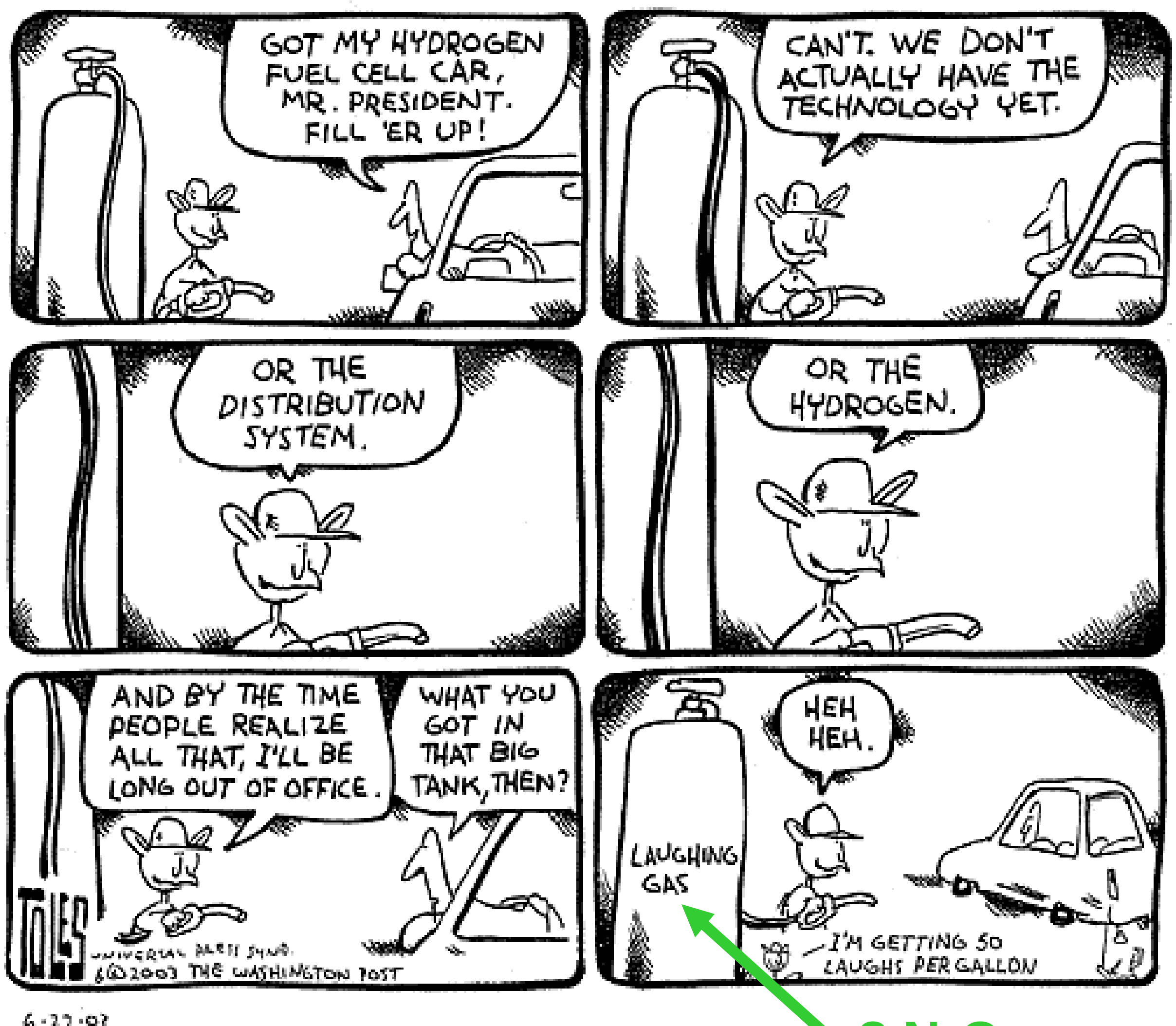
FreedomCAR and Fuel Initiative

H_2

"A simple chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car producing only water, not exhaust fumes. With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution-free. Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy."

— President Bush, State of the Union Address, January 28, 2003

The aura of a clean, hydrogen (H_2)-fueled future

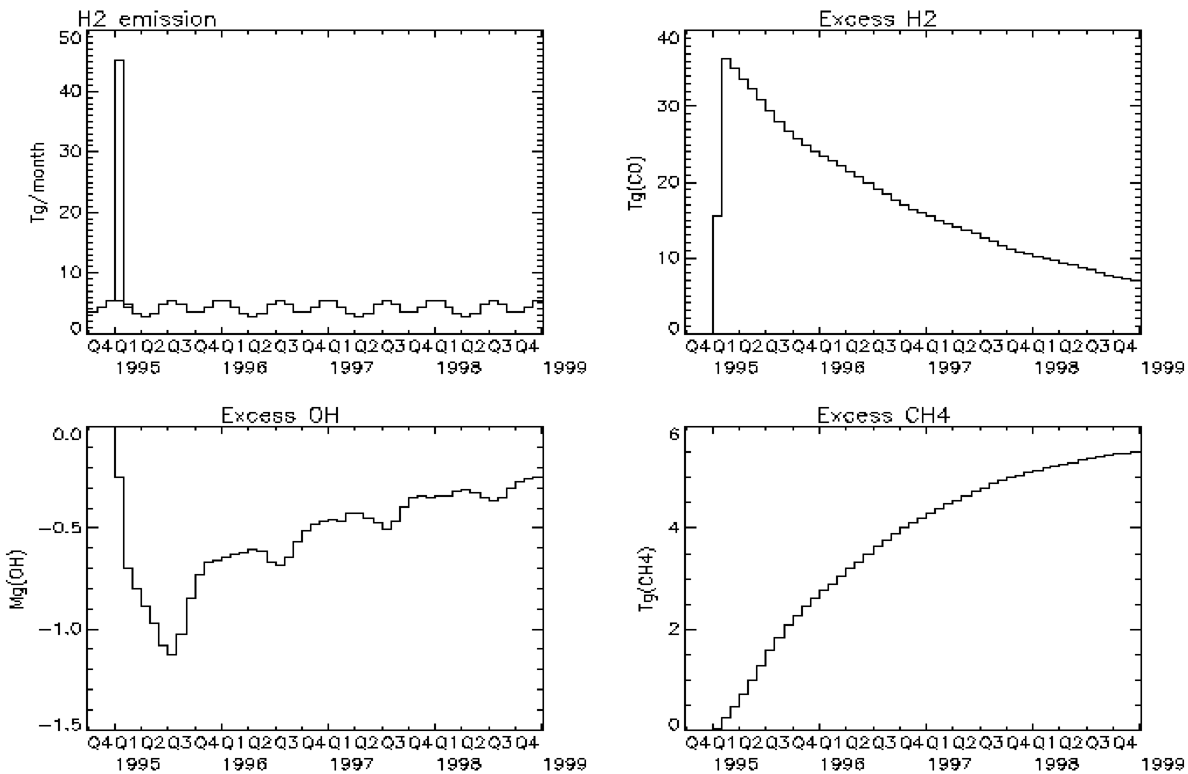


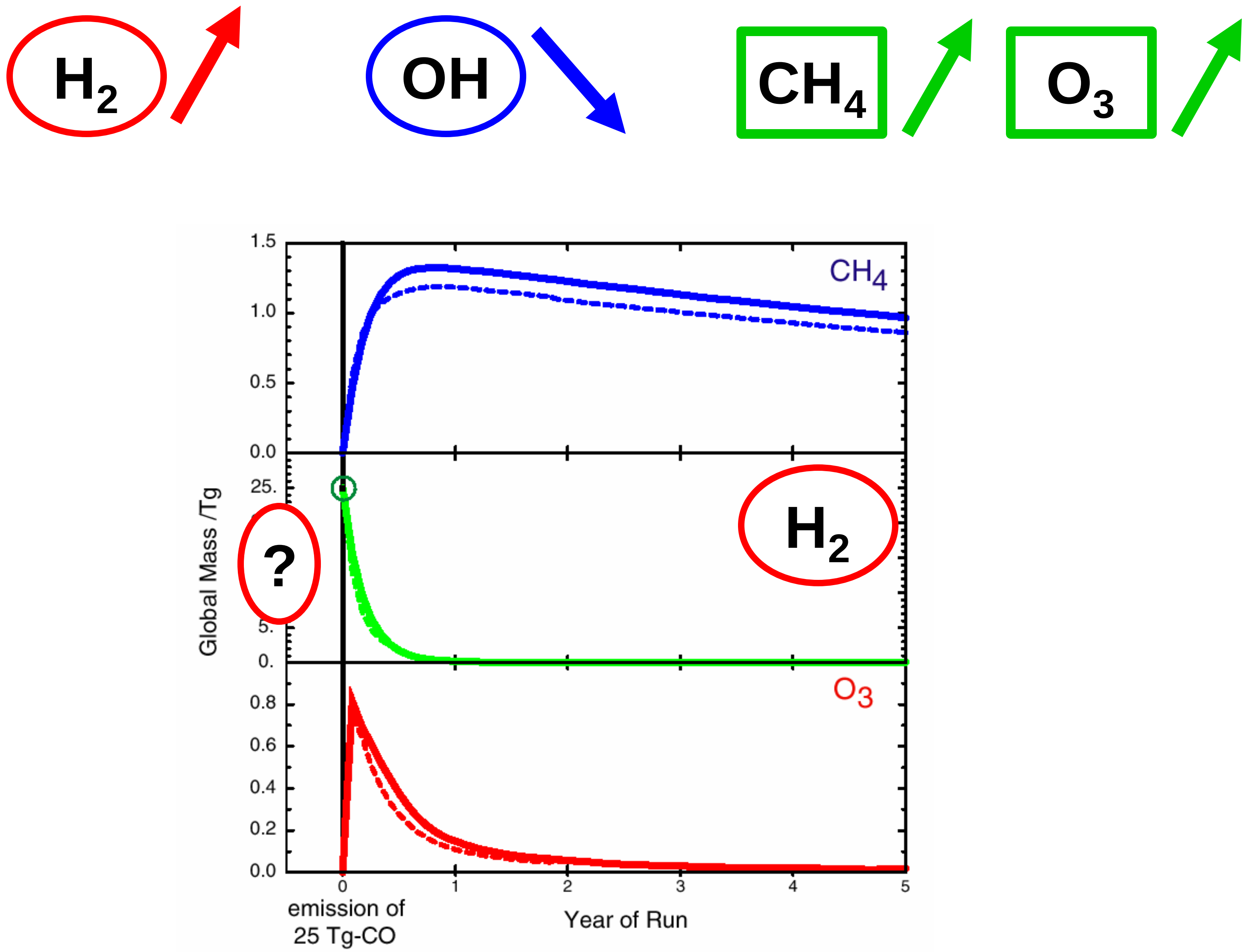
? N_2O, a greenhouse gas

CLIMATE IMPLICATIONS OF A HYDROGEN ECONOMY

Dick Derwent, Climate Research, The U.K. Met Office

2002





H_2
OH
CH_4
O_3
1.5
1.0
0.5
0.0
CH_4
25.
5.
0.
H_2
?
Global Mass /Tg
0.8
0.6
0.4
0.2
0.0
O_3
0
1
2
3
4
5
emission of
25 Tg-CO
Year of Run

CLIMATE IMPLICATIONS OF A HYDROGEN ECONOMY

Dick Derwent & Michael Prather

- H_2 is a greenhouse gas by virtue of its tropospheric chemistry and its role in changing the build-up of methane and ozone
- the global warming consequences of the global hydrogen economy will depend on the leakage rates for hydrogen manufacture, storage and distribution systems
- IPCC Working Group I report recognised that a future H_2 economy would act as a potential climate perturbation
- sustained H_2 increases of +1800 ppb require 315 Tg-H_2/yr, but yield 45 Tg-CH_4/yr, which on a GWP basis is much larger than all of aviation's CO_2 emissions.

STRATOSPHERIC IMPLICATIONS OF A HYDROGEN ECONOMY

REPORTS 13 JUNE 2003 VOL 300 SCIENCE www.sciencemag.org

Potential Environmental Impact of a Hydrogen Economy on the Stratosphere

Tracey K. Tromp,[1] Run-Lie Shia,[1] Mark Allen,[2] John M. Eiler,[1] Y. L. Yung[1]*

The widespread use of hydrogen fuel cells could have hitherto unknown environmental impacts due to unintended emissions of molecular hydrogen, including an increase in the abundance of water vapor in the stratosphere (plausibly by as much as ~1 part per million by volume). This would cause stratospheric cooling, enhancement of the heterogeneous chemistry that destroys ozone, an increase in noctilucent clouds, and changes in tropospheric chemistry and atmosphere-biosphere interactions.

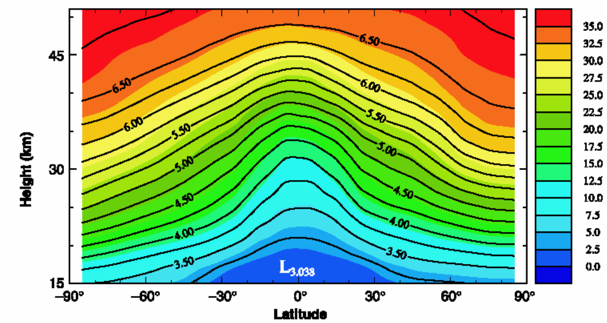


Fig. 2. The background H_2O mixing ratio (given by contours in units of ppmv) and the increase of stratospheric H_2O in January due to the assumed fourfold increase of H_2, computed using the Caltech/JPL 2-D model (given by color in % change). The altitude is defined as in Fig 1.

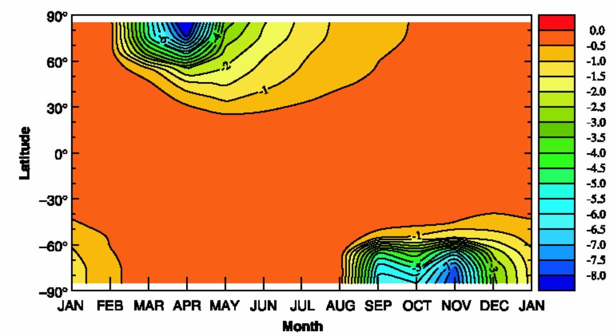
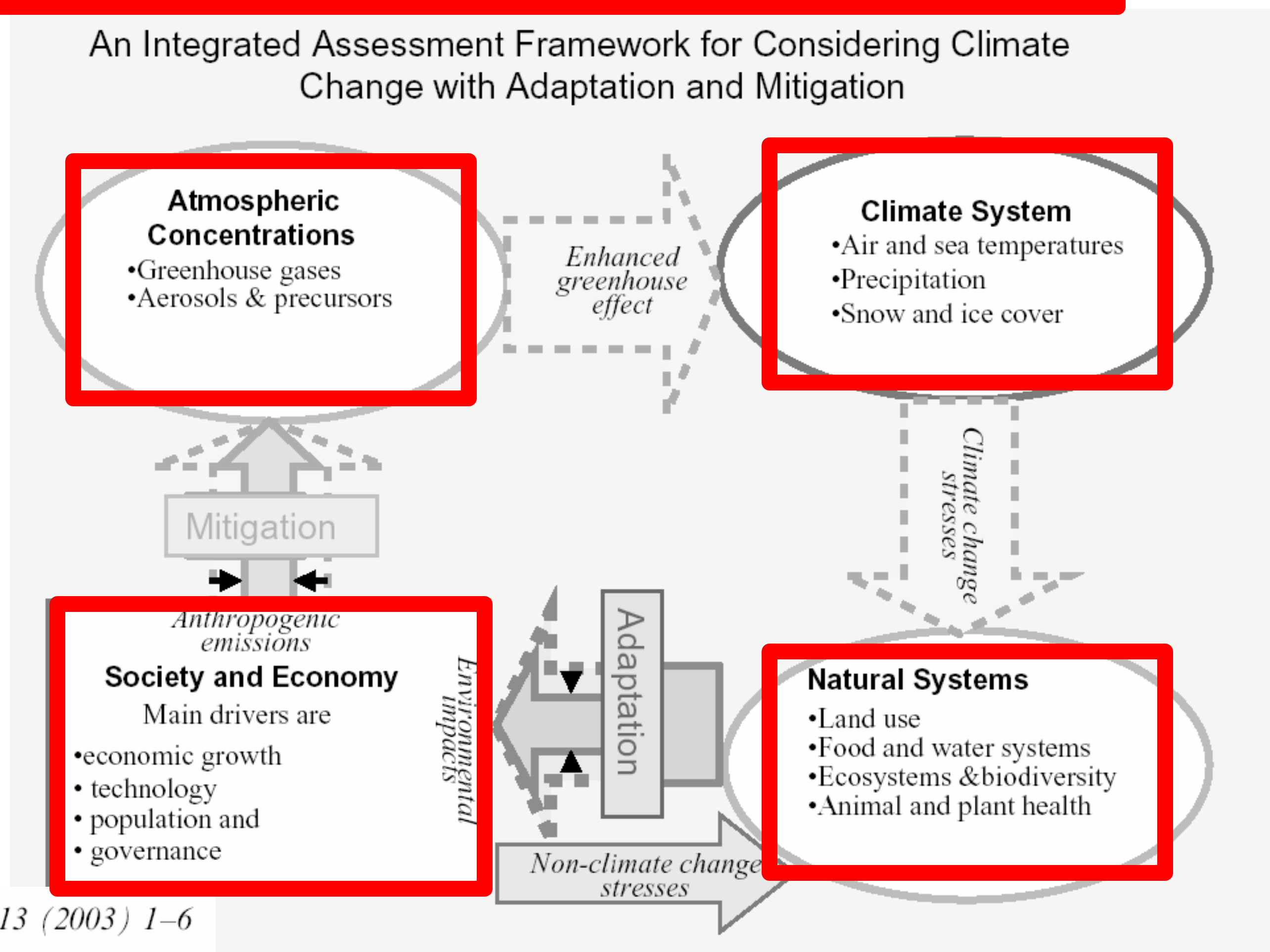


Fig. 3. Latitudinal and seasonal distribution of column ozone depletion (in %) due to an assumed fourfold increase of H_2, simulated by the Caltech/JPL 2-D model.

Climate change involves the entire Earth system:

Indirect effects / feedbacks on composition and climate forcing involve the physical climate system, natural and managed ecosystems, socio-economic development, on a global scale

-- NOT just anthropogenic emissions.



T. Barker / Global Environmental Change 13 (2003) 1–6